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Behroozi et al.

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(54) **DYNAMICALLY ADJUSTING WIDTH OF BEAM BASED ON ALTITUDE**

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H01Q 3/16 (2006.01)
H01Q 1/12 (2006.01)
H01Q 19/13 (2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 1/28*** (2013.01); ***H01Q 1/1264*** (2013.01); ***H01Q 3/16*** (2013.01); ***H01Q 19/13*** (2013.01)

(58) **Field of Classification Search**

CPC H01Q 1/1264; H01Q 1/28; H01Q 3/16
USPC 343/706, 761, 839, 840, 705, 757
See application file for complete search history.

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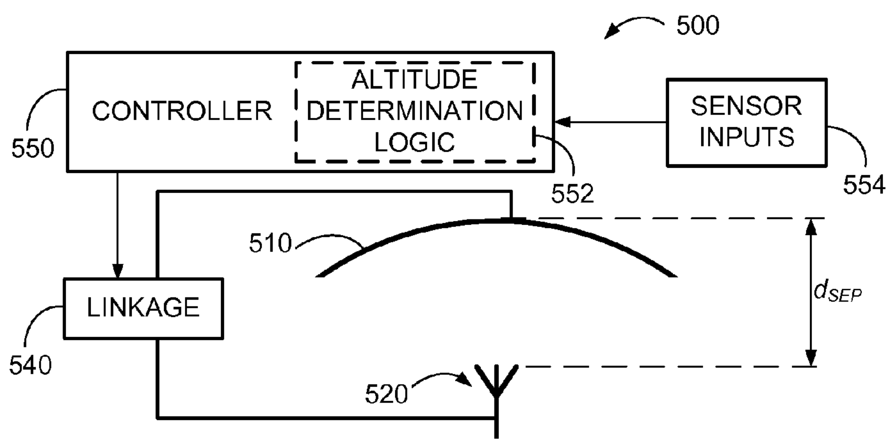
(57) **ABSTRACT**

An antenna includes a radiator and a reflector and has a radiation pattern that is based at least in part on a separation distance between the radiator and the reflector. The antenna includes a linkage configured to adjust the separation distance based at least in part on the altitude of the antenna. The resulting radiation pattern can be dynamically adjusted based on altitude of the antenna such that, while the antenna is aloft and the antenna is ground-facing, variations in geographic boundaries and intensity of the radiation received at ground level are at least partially compensated for by the dynamic adjustments to the radiation pattern.

20 Claims, 11 Drawing Sheets



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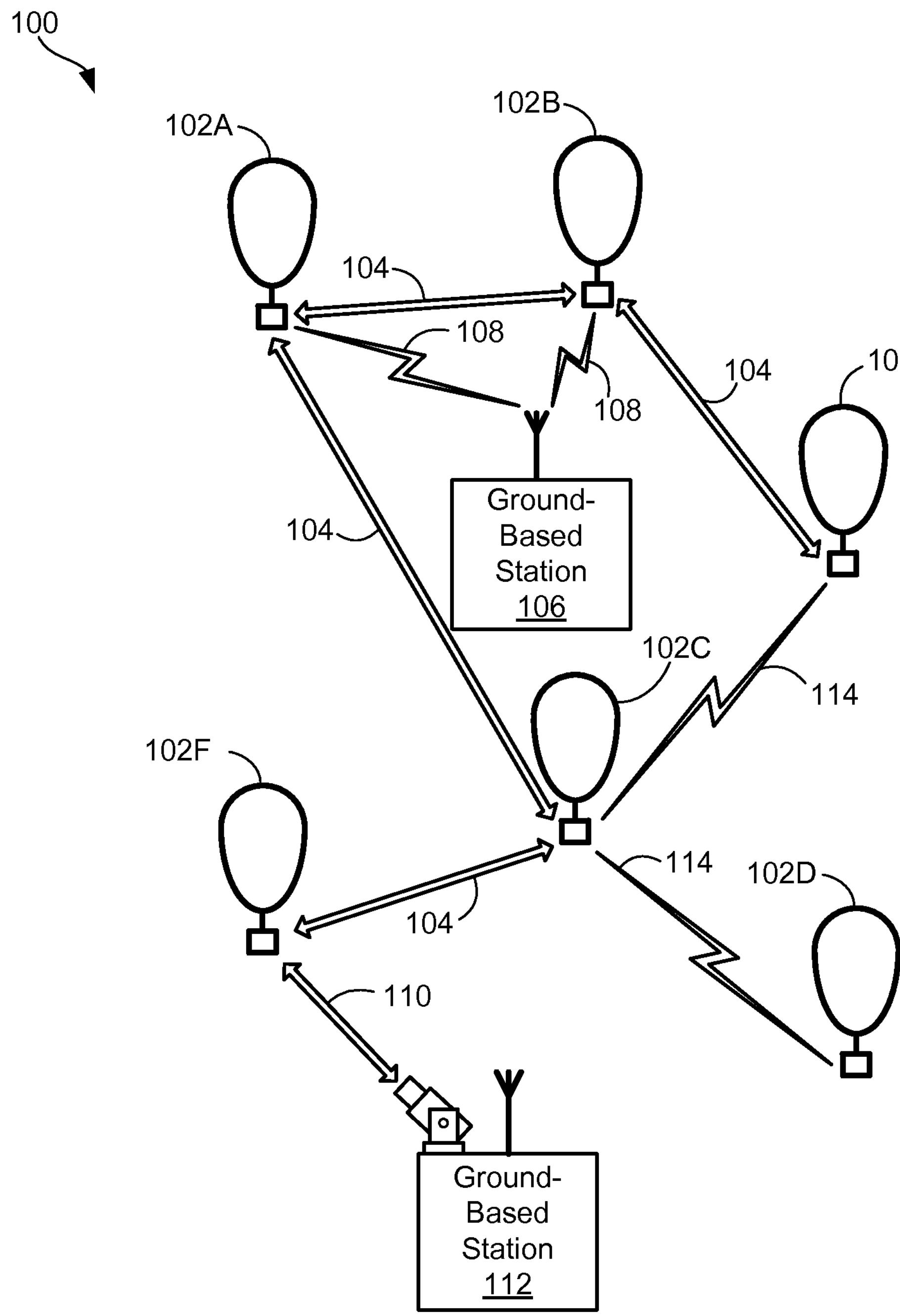
100
102A
102B
104
108
108
104
102E
104
Ground-Based Station 106
102C
114
102F
114
102D
104
110
Ground-Based Station 112

Figure 1

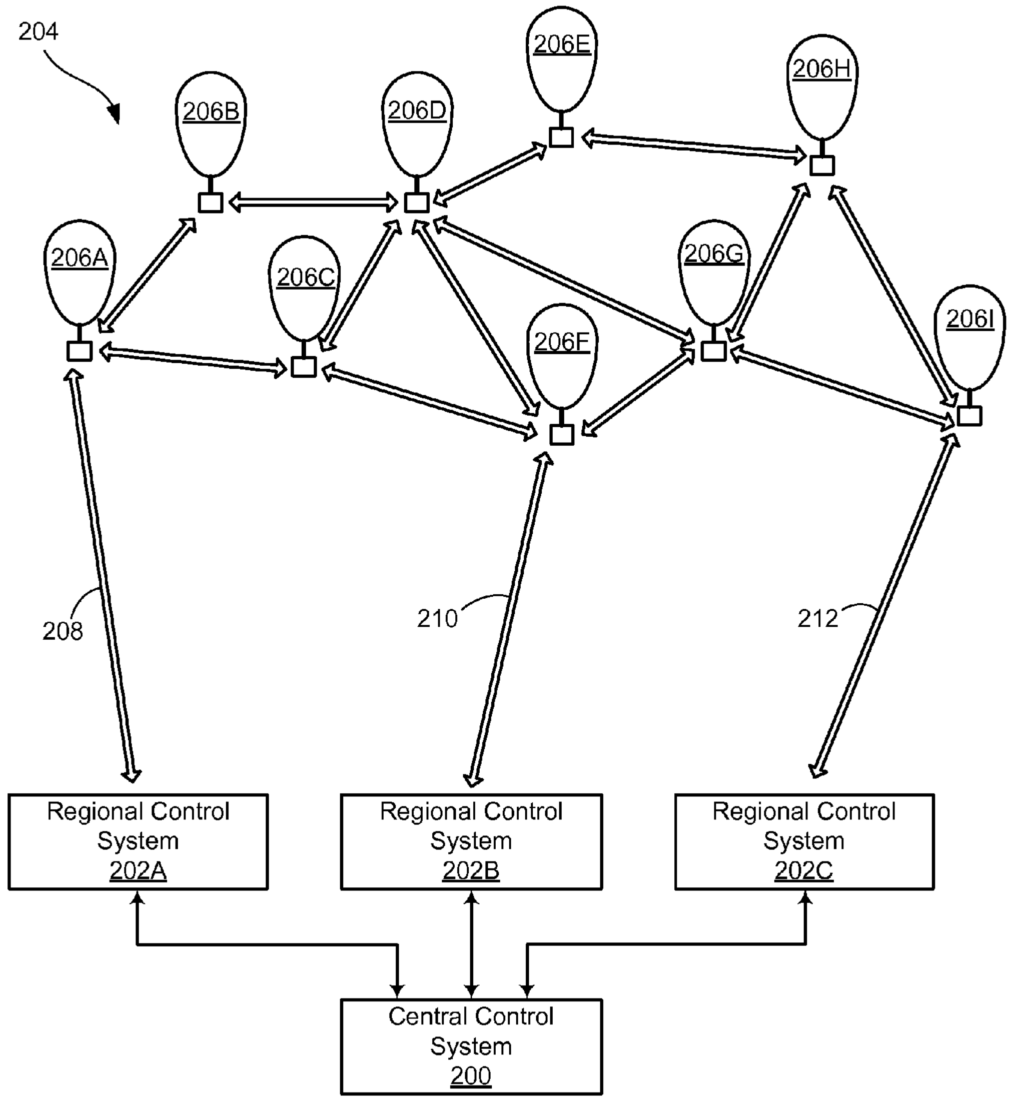
204
206A
206B
206C
206D
206E
206F
206G
206H
206I
208
210
212
Regional Control System 202A
Regional Control System 202B
Regional Control System 202C
Central Control System 200

Figure 2

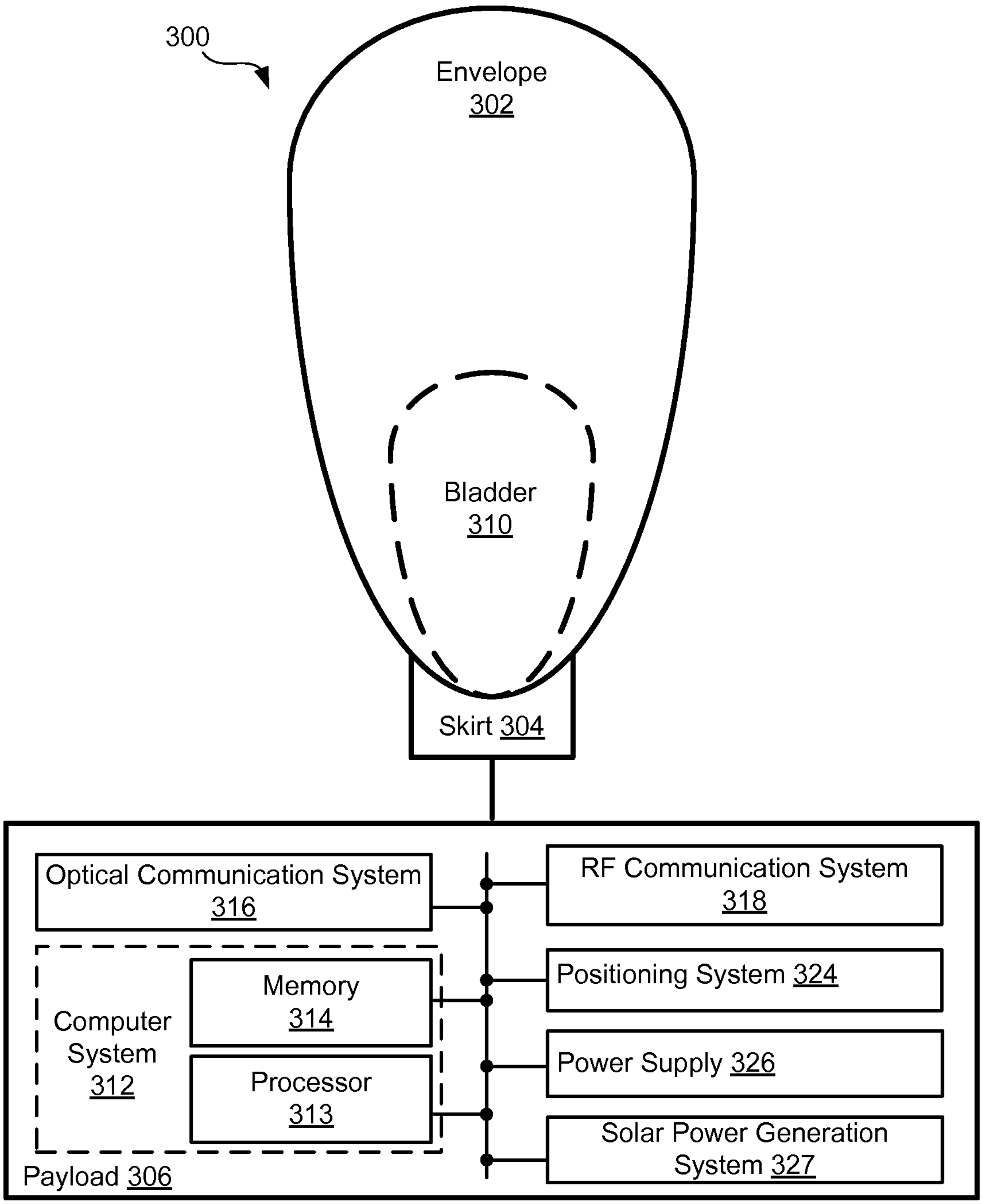
300
Envelope
302
Bladder
310
Skirt 304
Optical Communication System
316
RF Communication System
318
Computer
System
312
Memory
314
Processor
313
Positioning System 324
Power Supply 326
Solar Power Generation
System 327
Payload 306

Figure 3

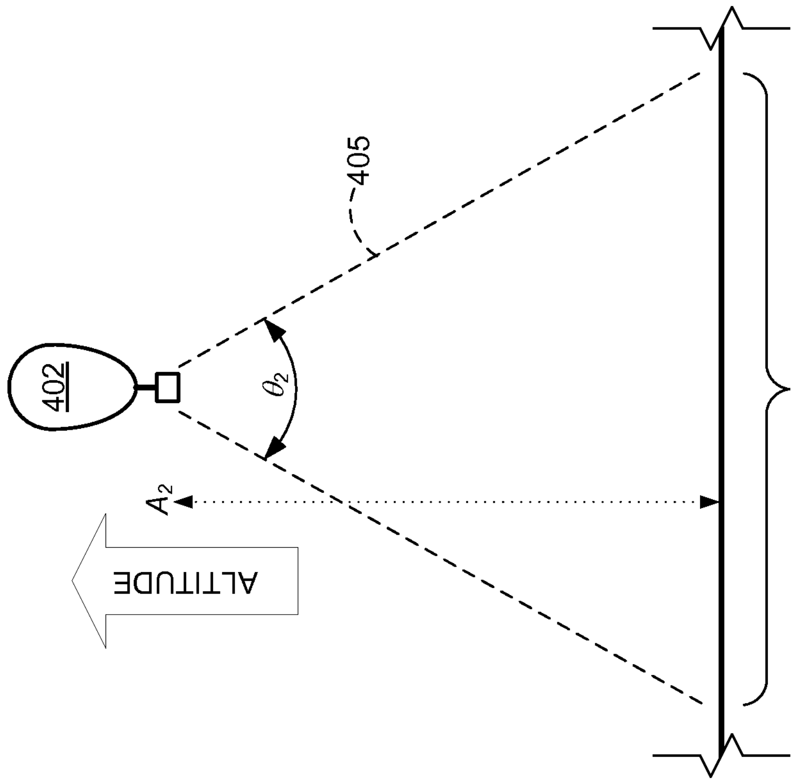

Figure 4B

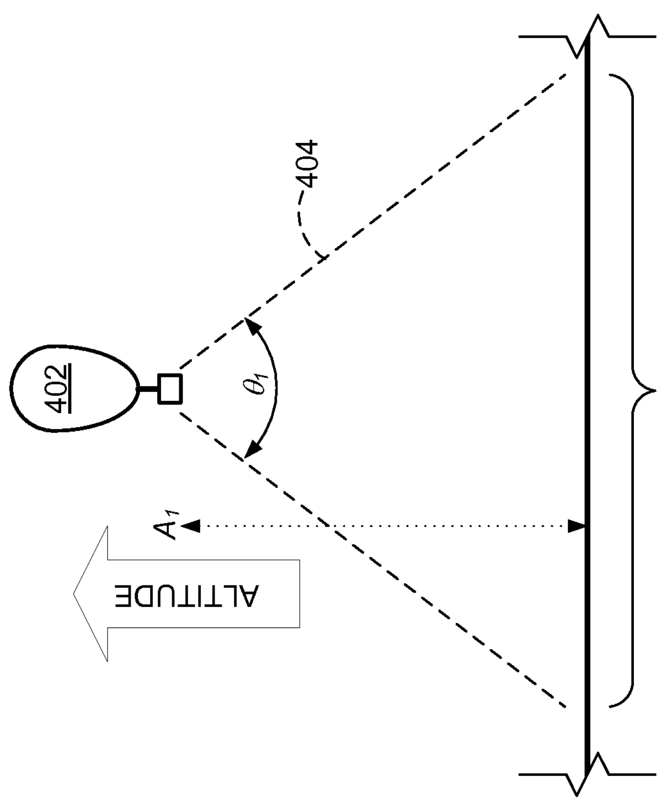

Figure 4A

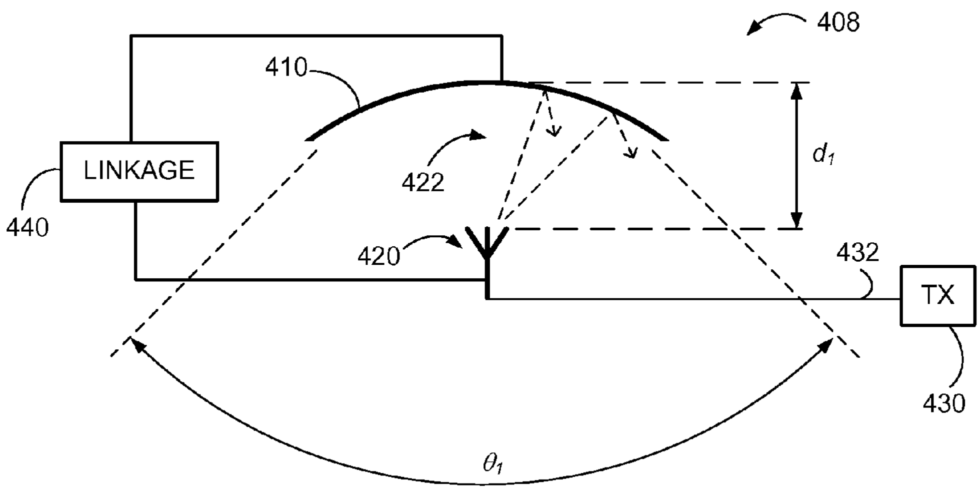

Figure 4C

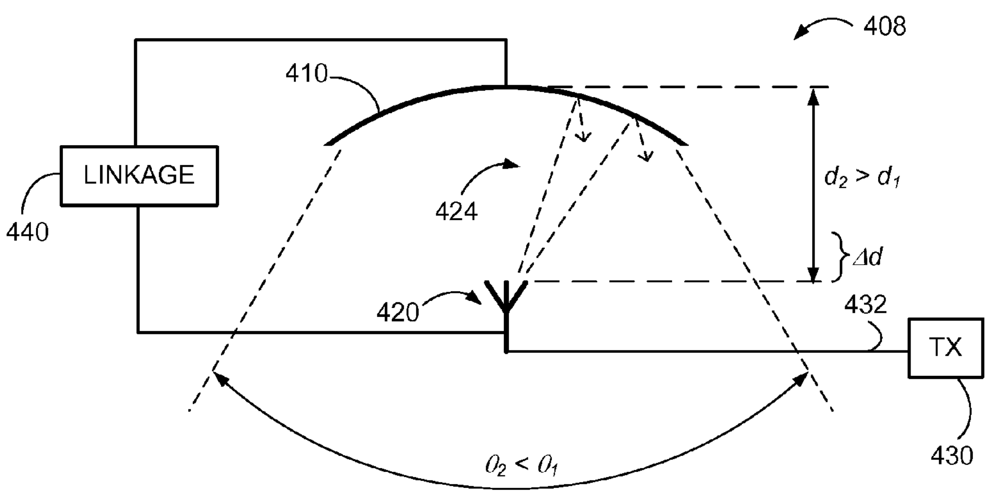

Figure 4D

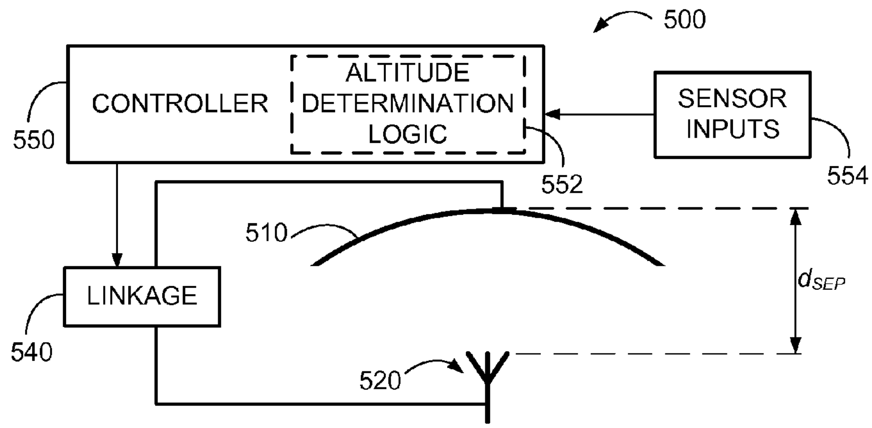

Figure 5A

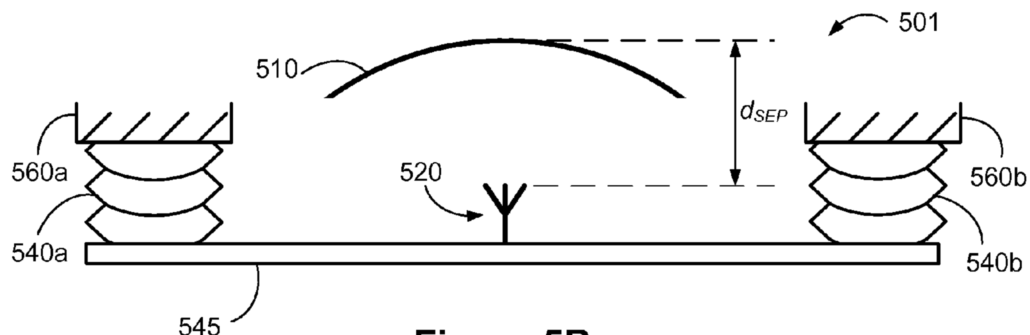

Figure 5B

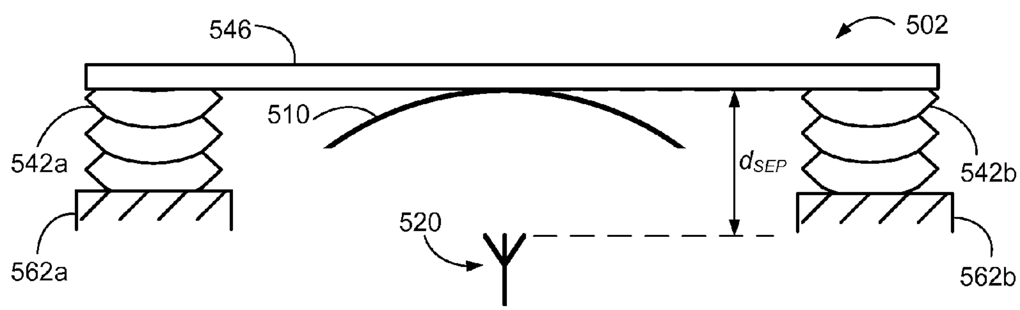

Figure 5C

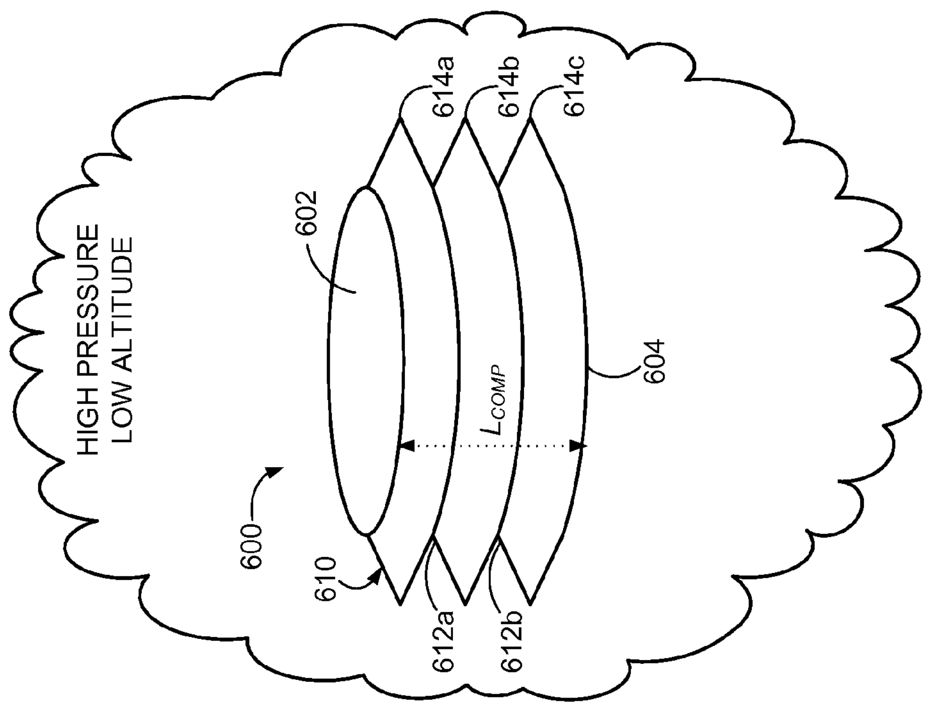

Figure 6B

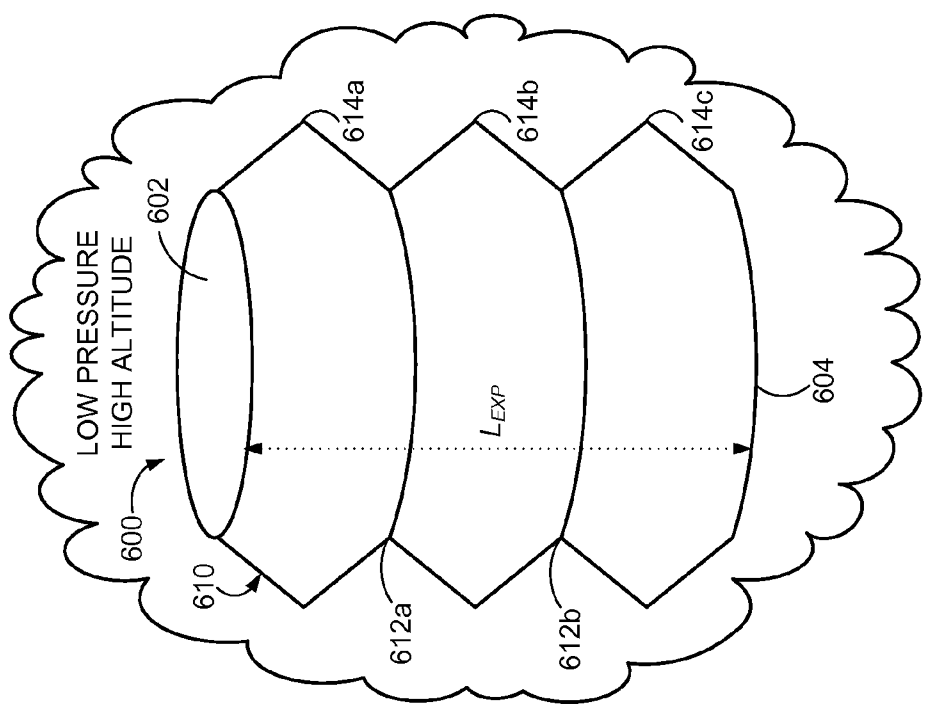

Figure 6A

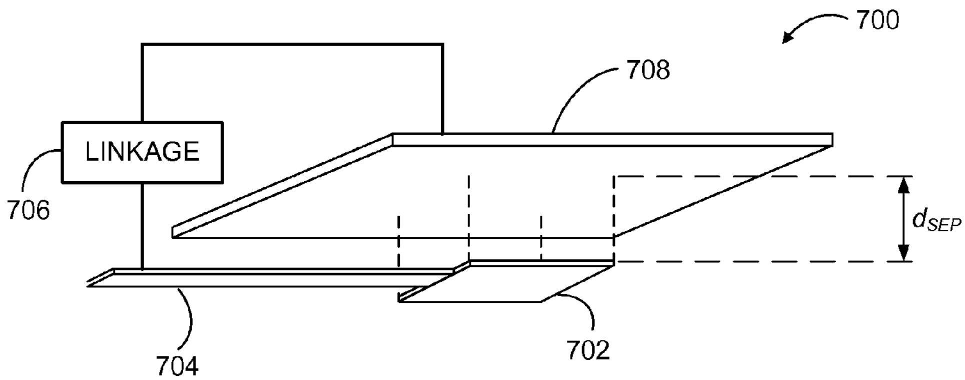

Figure 7A

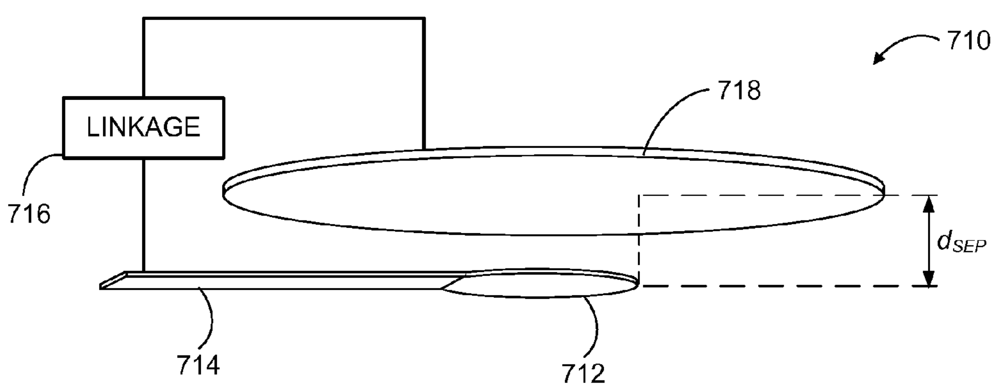

Figure 7B

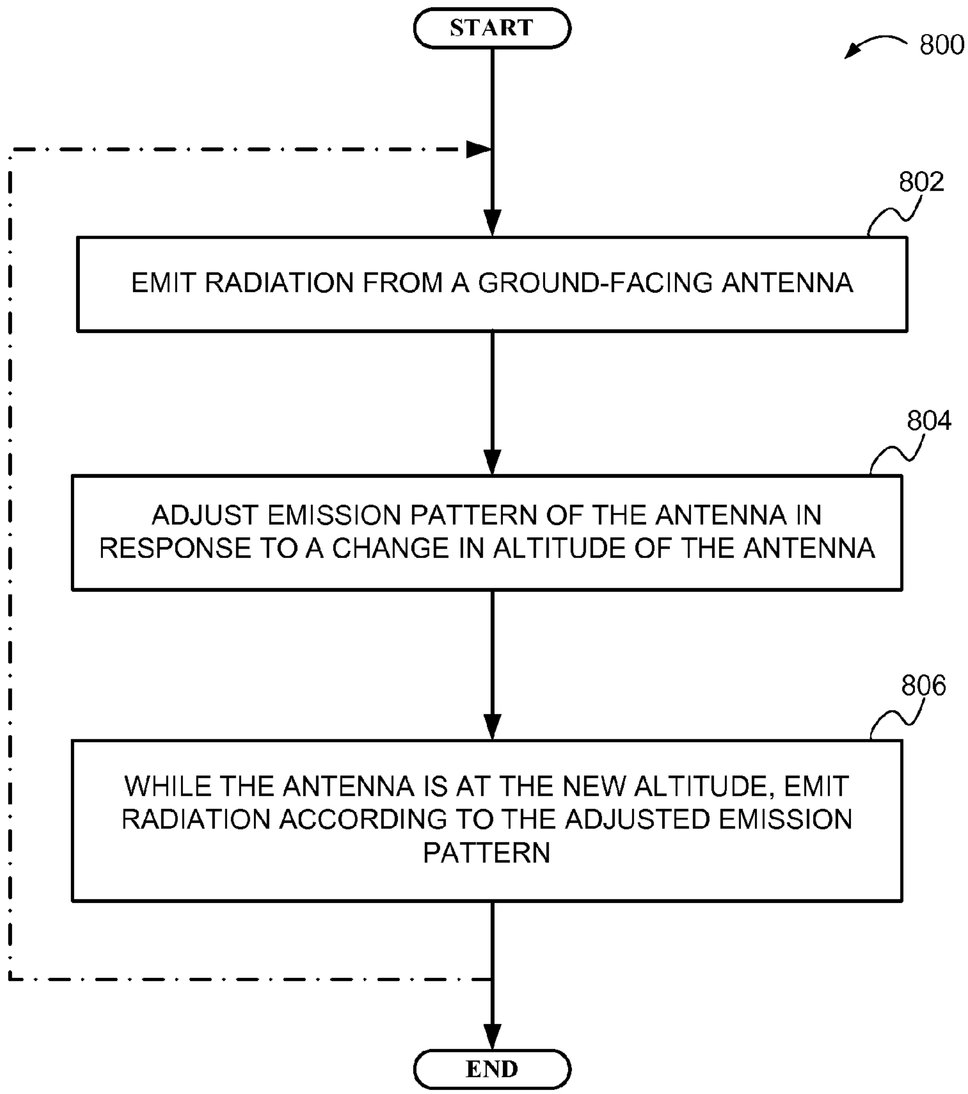
START
800
802
EMIT RADIATION FROM A GROUND-FACING ANTENNA
804
ADJUST EMISSION PATTERN OF THE ANTENNA IN RESPONSE TO A CHANGE IN ALTITUDE OF THE ANTENNA
806
WHILE THE ANTENNA IS AT THE NEW ALTITUDE, EMIT RADIATION ACCORDING TO THE ADJUSTED EMISSION PATTERN
END

Figure 8A

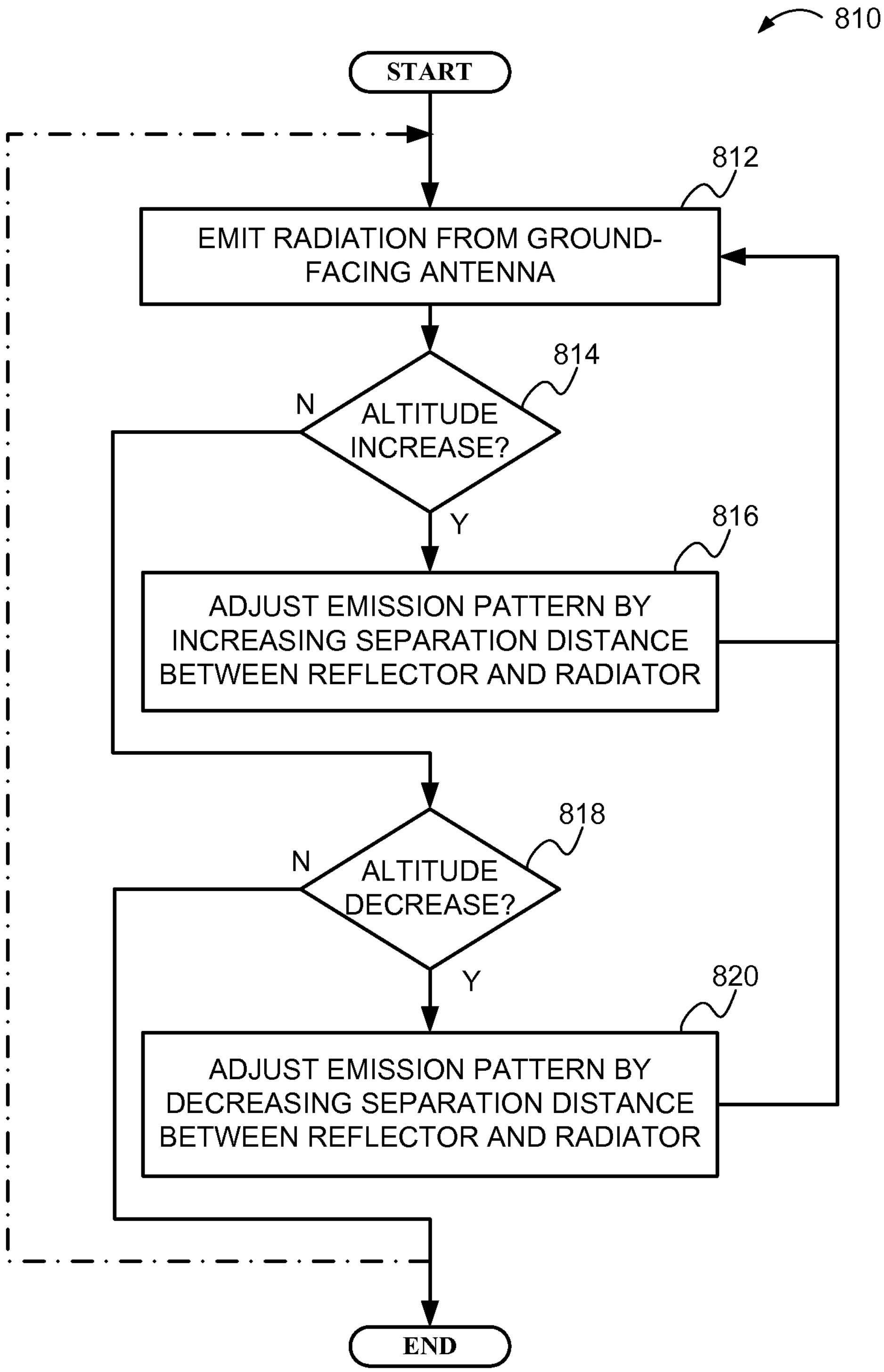
810
START
812
EMIT RADIATION FROM GROUND-FACING ANTENNA
814
ALTITUDE INCREASE?
N
Y
816
ADJUST EMISSION PATTERN BY INCREASING SEPARATION DISTANCE BETWEEN REFLECTOR AND RADIATOR
818
ALTITUDE DECREASE?
N
Y
820
ADJUST EMISSION PATTERN BY DECREASING SEPARATION DISTANCE BETWEEN REFLECTOR AND RADIATOR
END

Figure 8B

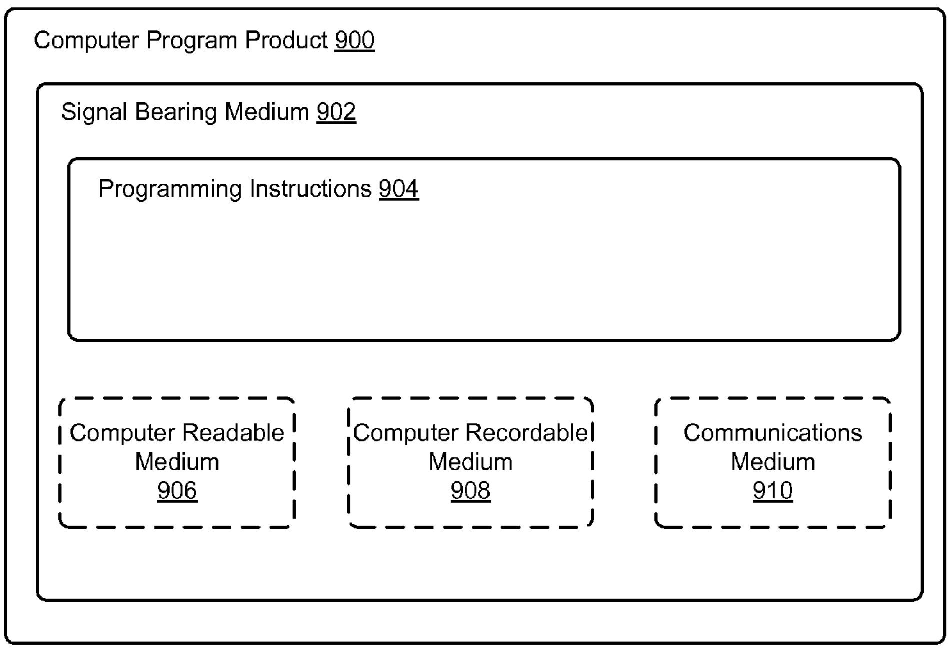
Computer Program Product 900
Signal Bearing Medium 902
Programming Instructions 904
Computer Readable Medium 906
Computer Recordable Medium 908
Communications Medium 910

Figure 9

DYNAMICALLY ADJUSTING WIDTH OF BEAM BASED ON ALTITUDE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. patent application Ser. No. 13/892,161, filed May 10, 2013, entitled "Dynamically Adjusting Width of Beam Based on Altitude", now pending, the contents of which are incorporated by reference herein for all purposes.

BACKGROUND

Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

Computing devices such as personal computers, laptop computers, tablet computers, cellular phones, and countless types of Internet-capable devices are increasingly prevalent in numerous aspects of modern life. As such, the demand for data connectivity via the Internet, cellular data networks, and other such networks, is growing. However, there are many areas of the world where data connectivity is still unavailable, or if available, is unreliable and/or costly.

SUMMARY

Example embodiments relate to a network of balloon-mounted ground-facing antennas for an aerial communication network. Balloons can be formed of an envelope supporting a payload with a power supply, data storage, and one or more transceivers for wirelessly communicating information to other members of the balloon network and/or to wireless stations located on the ground.

Some embodiments of the present disclosure provide an antenna configured to be mounted to a high altitude platform. The antenna can include a radiator, a reflector, and a linkage. The radiator can be configured to emit radiation according to a feed signal. The reflector configured to direct radiation emitted from the radiator such that reflected radiation is characterized by an emission pattern determined at least in part by a separation distance between the radiator and the reflector. The reflector can be configured to be situated such that the emission pattern is directed in a ground-facing direction while the associated high altitude platform is aloft. The linkage configured to adjust the separation distance between the radiator and the reflector according to an altitude of the associated high altitude platform.

Some embodiments of the present disclosure provide a balloon. The balloon can include an envelope, a payload configured to be suspended from the envelope, and an antenna. The antenna can be mounted to the payload and situated so as to be ground-facing while the balloon is aloft. The antenna can include: (i) a radiator configured to emit radiation according to feed signals; (ii) a reflector configured to direct the radiation emitted from the radiator according to a radiation pattern determined at least in part according to a separation distance between the radiator and the reflector; and (iii) a linkage configured to adjust the separation distance between the radiator and the reflector according to an altitude of the antenna.

Some embodiments of the present disclosure provide a method. The method can include emitting radiation from an antenna configured to be mounted to a payload of an

associated balloon. The antenna can have an emission pattern determined at least in part by a separation distance between a radiator and a reflector of the antenna. The antenna can be configured to be situated such that the emission pattern is directed in a ground-facing direction while the associated balloon is aloft and the antenna is mounted to the payload. The method can include decreasing the separation distance between the radiator and the reflector responsive to a decrease in altitude of the associated balloon. The method can include increasing the separation distance between the radiator and the reflector responsive to an increase in altitude of the associated balloon.

Some embodiments of the present disclosure provide means for emitting radiation from an antenna configured to be mounted to a payload of an associated balloon. The antenna can have an emission pattern determined at least in part by a separation distance between a radiator and a reflector of the antenna. The antenna can be configured to be situated such that the emission pattern is directed in a ground-facing direction while the associated balloon is aloft and the antenna is mounted to the payload. Some embodiments can include means for decreasing the separation distance between the radiator and the reflector responsive to a decrease in altitude of the associated balloon. Some embodiments can include means for increasing the separation distance between the radiator and the reflector responsive to an increase in altitude of the associated balloon.

These as well as other aspects, advantages, and alternatives, will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a simplified block diagram illustrating a balloon network, according to an example embodiment.

FIG. **2** is a block diagram illustrating a balloon-network control system, according to an example embodiment.

FIG. **3** is a simplified block diagram illustrating a high-altitude balloon, according to an example embodiment.

FIG. **4**A is a diagram of a balloon with a downward-facing antenna situated to illuminate a geographic region from a first elevation.

FIG. **4**B is a diagram of the balloon in FIG. **4**A illuminating the geographic region from a second elevation.

FIG. **4**C is a side view diagram of an antenna configured to illuminate a broad emission pattern.

FIG. **4**D is a side view diagram of an antenna configured to illuminate a narrow emission pattern.

FIG. **5**A is a simplified block diagram of an antenna with a dynamically adjustable emission pattern.

FIG. **5**B is a simplified block diagram of another antenna with a dynamically adjustable emission pattern.

FIG. **5**C is a simplified block diagram of another antenna with a dynamically adjustable emission pattern.

FIG. **6**A shows a pressure-sensitive vessel in an expanded state.

FIG. **6**B shows the pressure-sensitive vessel in a contracted state.

FIG. **7**A is a simplified diagram of an antenna with a flat reflector.

FIG. **7**B is a simplified diagram of another antenna with a flat reflector.

FIG. **8**A is a flowchart of a process for dynamically adjusting an antenna emission pattern according to an example embodiment.

FIG. **8**B is a flowchart of a process for dynamically adjusting an antenna emission pattern according to an example embodiment.

FIG. **9** illustrates a computer readable medium according to an example embodiment.

DETAILED DESCRIPTION

Example methods and systems are described herein. Any example embodiment or feature described herein is not necessarily to be construed as preferred or advantageous over other embodiments or features. The example embodiments described herein are not meant to be limiting. It will be readily understood that certain aspects of the disclosed systems and methods can be arranged and combined in a wide variety of different configurations, all of which are contemplated herein.

1. Overview

Example embodiments relate to an aerial communication network using a plurality of balloons with communication equipment to facilitate wireless communication with ground-based stations and among the balloons. Balloons can be formed of an envelope supporting a payload with a power supply, data storage, and one or more transceivers for wirelessly communicating information to other members of the balloon network and/or to wireless stations located on the ground. To communicate with ground-based stations while aloft, the balloons can be equipped with antennas mounted to the balloon payload so as to be ground-facing.

A ground-facing antenna can include a radiating element situated to radiate toward a reflector. The reflector may be a dish, such as a quasi-parabolic dish that may be spherically invariant. The radiating element can emit signals toward the reflector, which results in radiation emitted from the antenna with a directional emission pattern. The directional emission pattern can be approximated as a cone-shaped region with an apex located near the antenna. The directivity of the emission pattern is thus determined by the breadth or narrowness of the region illuminated by the emission pattern, and can be characterized by an opening angle of the conical surface bounding the illuminated region. The opening angle (and thus the antenna directivity) is determined, at least in part, by the separation distance between the radiating element and the reflector. Generally, a greater separation distance corresponds to a narrower emission pattern, whereas a lesser separation distance corresponds to a broader emission pattern.

In some examples, the emission pattern can be adjusted as the balloon changes altitude. For example, the radiating element in the antenna can be moved closer or further from the reflector to dynamically adjust the width of the emission pattern based on the altitude of the balloon. A control system can determine the altitude of the balloon and then cause the separation distance between the radiating element and the reflector to be adjusted according to the determined altitude.

In some examples, a pressure-sensitive vessel that expands and contracts as the balloon changes altitude based on the atmospheric pressure can be included in a linkage that mounts the radiator and/or reflector to the balloon payload. The expansion and contraction of the vessel can thus expand or contract or the linkage and thereby passively adjust the separation distance as the altitude varies.

The emission pattern may be adjusted to account for variations in the emitted radiation at ground level due to altitude changes of the balloon. Such adjustments may be carried out to cause the width of the emission pattern at ground level to be substantially unchanged even while the balloon altitude varies. Additionally or alternatively, adjustments may be carried out to cause the intensity of the emission pattern at ground level to be substantially unchanged even while the balloon altitude varies.

Each of these specific methods and systems are contemplated herein, and several example embodiments are described below.

2. Example Systems

FIG. **1** is a simplified block diagram illustrating a balloon network **100**, according to an example embodiment. As shown, balloon network **100** includes balloons **102**A to **102**F, which are configured to communicate with one another via free-space optical links **104** (e.g., by sending and receiving optical radiation encoded with data). Moreover, while referred to as "optical," communication on the optical links **104** may be carried out with radiation at a range of wavelengths including radiation outside the visible spectrum, such as infrared radiation, ultraviolet radiation, etc. Balloons **102**A to **102**F could additionally or alternatively be configured to communicate with one another via radio frequency (RF) links **114** (e.g., by sending and receiving radio frequency radiation encoded with data). Balloons **102**A to **102**F may collectively function as a mesh network for packet-data communications. Further, at least some balloons (e.g., **102**A and **102**B) may be configured for RF communications with a ground-based station **106** via respective RF links **108**. Further, some balloons, such as balloon **102**F, could be configured to communicate via optical link **110** with a suitably equipped ground-based station **112**.

In an example embodiment, balloons **102**A to **102**F are high-altitude balloons, which are deployed in the stratosphere. At moderate latitudes, the stratosphere includes altitudes between approximately 10 kilometers (km) and 50 km altitude above the surface of the Earth. At the poles, the stratosphere starts at an altitude of approximately 8 km. In an example embodiment, high-altitude balloons may be generally configured to operate in an altitude range within the stratosphere that has relatively low wind speed (e.g., between 8 and 32 kilometers per hour (kph)).

More specifically, in a high-altitude-balloon network, balloons **102**A to **102**F may generally be configured to operate at altitudes between 18 km and 25 km (although other altitudes are possible). This altitude range may be advantageous for several reasons. In particular, this altitude region of the stratosphere generally has relatively desirable atmospheric conditions with low wind speeds (e.g., winds between 8 and 32 kph) and relatively little turbulence. Further, while winds between altitudes of 18 km and 25 km may vary with latitude and by season, the variations can be modeled with reasonably accuracy and thereby allow for predicting and compensating for such variations. Additionally, altitudes above 18 km are typically above the maximum altitude designated for commercial air traffic.

To transmit data to another balloon, a given balloon **102**A to **102**F may be configured to transmit an optical signal via an optical link **104**. In an example embodiment, a given balloon **102**A to **102**F may use one or more high-power light-emitting diodes (LEDs) to transmit an optical signal. Alternatively, some or all of balloons **102**A to **102**F may include laser systems for free-space optical communications over optical links **104**. Other types of free-space optical communication are possible. Further, in order to receive an optical signal from another balloon via an optical link **104**, a given balloon **102**A to **102**F may include one or more optical receivers.

In a further aspect, balloons **102**A to **102**F may utilize one or more of various different RF air-interface protocols for communication with ground-based stations **106** and **112** via respective RF links **108**. For instance, some or all of balloons **102**A to **102**F may be configured to communicate with ground-based stations **106** and **112** using protocols described in IEEE 802.11 (including any of the IEEE 802.11 revisions), various cellular protocols such as GSM, CDMA, UMTS, EV-DO, WiMAX, and/or LTE, and/or one or more propriety protocols developed for balloon-ground RF communication, among other possibilities.

In a further aspect, there may be scenarios where RF links **108** do not provide a desired link capacity for balloon-to-ground communications. For instance, increased capacity may be desirable to provide backhaul links from a ground-based gateway, and in other scenarios as well. Accordingly, an example network may also include one or more downlink balloons, which could provide a high-capacity air-ground link to connect the balloon network **100** to ground-based network elements.

For example, in balloon network **100**, balloon **102**F is configured as a downlink balloon. Like other balloons in an example network, the downlink balloon **102**F may be operable for optical communication with other balloons via optical links **104**. However, the downlink balloon **102**F may also be configured for free-space optical communication with a ground-based station **112** via an optical link **110**. Optical link **110** may therefore serve as a high-capacity link (as compared to an RF link **108**) between the balloon network **100** and the ground-based station **112**.

Note that in some implementations, the downlink balloon **102**F may additionally be operable for RF communication with ground-based stations **106**. In other cases, the downlink balloon **102**F may only use an optical link for balloon-to-ground communications. Further, while the arrangement shown in FIG. **1** includes just one downlink balloon **102**F, an example balloon network can also include multiple downlink balloons. On the other hand, a balloon network can also be implemented without any downlink balloons.

In other implementations, a downlink balloon may be equipped with a specialized, high-bandwidth RF communication system for balloon-to-ground communications, instead of, or in addition to, a free-space optical communication system. The high-bandwidth RF communication system may take the form of an ultra-wideband system, which may provide an RF link with substantially the same capacity as one of the optical links **104**. Other forms are also possible.

Ground-based stations, such as ground-based stations **106** and/or **112**, may take various forms. Generally, a ground-based station may include components such as transceivers, transmitters, and/or receivers for wireless communication via RF links and/or optical links with corresponding transceivers situated on balloons in the balloon network **100**. Further, a ground-based station may use various air-interface protocols to communicate with balloons **102**A to **102**F over an RF link **108**. As such, ground-based stations **106** and **112** may be configured as an access point via which various devices can connect to balloon network **100**. Ground-based stations **106** and **112** may have other configurations and/or serve other purposes without departing from the scope of the present disclosure.

In a further aspect, some or all of balloons **102**A to **102**F could be additionally or alternatively configured to establish a communication link with space-based satellites. In some embodiments, a balloon may communicate with a satellite via an optical link. However, other types of satellite communications are possible.

Further, some ground-based stations, such as ground-based stations **106** and **112**, may be configured as gateways between balloon network **100** and one or more other networks. Such ground-based stations **106** and **112** may thus serve as an interface between the balloon network and the Internet, a cellular service provider's network, and/or other types of networks for communicating information. Variations on this configuration and other configurations of ground-based stations **106** and **112** are also possible.

2a) Mesh Network Functionality

As noted, balloons **102**A to **102**F may collectively function as a mesh network. More specifically, since balloons **102**A to **102**F may communicate with one another using free-space optical links, the balloons may collectively function as a free-space optical mesh network.

In a mesh-network configuration, each balloon **102**A to **102**F may function as a node of the mesh network, which is operable to receive data directed to it and to route data to other balloons. As such, data may be routed from a source balloon to a destination balloon by determining an appropriate sequence of optical links between the source balloon and the destination balloon. These optical links may be collectively referred to as a "lightpath" for the connection between the source and destination balloons. Further, each of the optical links may be referred to as a "hop" on the lightpath. Each intermediate balloon (i.e., hop) along a particular lightpath may act as a repeater station to first detect the incoming communication via received optical signals and then repeat the communication by emitting a corresponding optical signal to be received by the next balloon on the particular lightpath. Additionally or alternatively, a particular intermediate balloon may merely direct incident signals toward the next balloon, such as by reflecting the incident optical signals to propagate toward the next balloon.

To operate as a mesh network, balloons **102**A to **102**F may employ various routing techniques and self-healing algorithms. In some embodiments, the balloon network **100** may employ adaptive or dynamic routing, where a lightpath between a source and destination balloon is determined and set-up when the connection is needed, and released at a later time. Further, when adaptive routing is used, the lightpath may be determined dynamically depending upon the current state, past state, and/or predicted state of the balloon network **100**.

In addition, the network topology may change as the balloons **102**A to **102**F move relative to one another and/or relative to the ground. Accordingly, an example balloon network **100** may apply a mesh protocol to update the state of the network as the topology of the network changes. For example, to address the mobility of the balloons **102**A to **102**F, balloon network **100** may employ and/or adapt various techniques that are employed in mobile ad hoc networks (MANETs). Other examples are possible as well.

In some implementations, the balloon network **100** may be configured as a transparent mesh network. More specifically, in a transparent mesh network configuration, the balloons may include components for physical switching that are entirely optical, without any electrical components involved in the routing of optical signals. Thus, in a transparent configuration with optical switching, signals can travel through a multi-hop lightpath that is entirely optical.

In other implementations, the balloon network **100** may implement a free-space optical mesh network that is opaque. In an opaque configuration, some or all balloons **102**A to **102**F may implement optical-electrical-optical (OEO) switching. For example, some or all balloons may include optical cross-connects (OXCs) for OEO conversion of optical signals. Other opaque configurations are also possible.

Additionally, network configurations are possible that include routing paths with both transparent and opaque sections.

In a further aspect, balloons in the balloon network **100** may implement wavelength division multiplexing (WDM), which may be used to increase link capacity. When WDM is implemented with transparent switching, it may be necessary to assign the same wavelength for all optical links on a given lightpath. Lightpaths in transparent balloon networks are therefore said to be subject to a "wavelength continuity constraint," because each hop in a particular lightpath may be required to use the same wavelength.

An opaque configuration, on the other hand, may avoid such a wavelength continuity constraint. In particular, balloons in an opaque balloon network may include OEO switching systems operable for wavelength conversions along a given lightpath. As a result, balloons can convert the wavelength of an optical signal at one or more hops along a particular lightpath.

2b) Control of Balloons in a Balloon Network

In some embodiments, mesh networking and/or other control functions may be centralized. For example, FIG. **2** is a block diagram illustrating a balloon-network control system, according to an example embodiment. In particular, FIG. **2** shows a distributed control system, which includes a central control system **200** and a number of regional control-systems **202**A to **202**B. Such a control system may be configured to coordinate certain functionality for balloon network **204**, and as such, may be configured to control and/or coordinate certain functions for balloons **206**A to **206**I.

In the illustrated embodiment, central control system **200** may be configured to communicate with balloons **206**A to **206**I via a number of regional control systems **202**A to **202**C. These regional control systems **202**A to **202**C may be configured to receive communications and/or aggregate data from balloons in the respective geographic areas that they cover, and to relay the communications and/or data to central control system **200**. Further, regional control systems **202**A to **202**C may be configured to route communications from central control system **200** to the balloons in their respective geographic areas. For instance, as shown in FIG. **2**, regional control system **202**A may relay communications and/or data between balloons **206**A to **206**C and central control system **200**, regional control system **202**B may relay communications and/or data between balloons **206**D to **206**F and central control system **200**, and regional control system **202**C may relay communications and/or data between balloons **206**G to **206**I and central control system **200**.

In order to facilitate communications between the central control system **200** and balloons **206**A to **206**I, certain balloons may be configured as downlink balloons, which are operable to communicate with regional control systems **202**A to **202**C. Accordingly, each regional control system **202**A to **202**C may be configured to communicate with the downlink balloon or balloons in the respective geographic area it covers. For example, in the illustrated embodiment, balloons **206**A, **206**F, and **206**I are configured as downlink balloons. As such, regional control systems **202**A to **202**C may respectively communicate with balloons **206**A, **206**F, and **206**I via optical links **206**, **208**, and **210**, respectively.

In the illustrated configuration, only some of balloons **206**A to **206**I are configured as downlink balloons. The balloons **206**A, **206**F, and **206**I that are configured as downlink balloons may relay communications from central control system **200** to other balloons in the balloon network, such as balloons **206**B to **206**E, **206**G, and **206**H. However, it should be understood that in some implementations, it is possible that all balloons may function as downlink balloons. Further, while FIG. **2** shows multiple balloons configured as downlink balloons, it is also possible for a balloon network to include only one downlink balloon.

The regional control systems **202**A to **202**C may be particular types of ground-based stations that are configured to communicate with downlink balloons (e.g., such as ground-based station **112** of FIG. **1**). Thus, while not shown in FIG. **2**, a control system may be implemented in conjunction with other types of ground-based stations (e.g., access points, gateways, etc.).

In a centralized control arrangement, such as that shown in FIG. **2**, the central control system **200** (and possibly regional control systems **202**A to **202**C as well) may coordinate certain mesh-networking functions for balloon network **204**. For example, balloons **206**A to **206**I may send the central control system **200** certain state information, which the central control system **200** may utilize to determine the state of balloon network **204**. The state information from a given balloon may include location data, optical-link information (e.g., the identity of other balloons with which the balloon has established an optical link, the bandwidth of the link, wavelength usage and/or availability on a link, etc.), wind data collected by the balloon, and/or other types of information. Accordingly, the central control system **200** may aggregate state information from some or all of the balloons **206**A to **206**I in order to determine an overall state of the network **204**.

Based in part on the overall state of the network **204**, the control system **200** may then be used to coordinate and/or facilitate certain mesh-networking functions, such as determining lightpaths for connections, for example. The central control system **200** may determine a current topology (or spatial distribution of balloons) based on the aggregate state information from some or all of the balloons **206**A to **206**I. The topology may indicate the current optical links that are available in the balloon network and/or the wavelength availability on such links. The topology may then be sent to some or all of the balloons so that individual balloons are enabled to select appropriate lightpaths (and possibly backup lightpaths) for communications through the balloon network **204** as needed.

In a further aspect, the central control system **200** (and possibly regional control systems **202**A to **202**C as well) may also coordinate certain positioning functions for balloon network **204** to achieve a desired spatial distribution of balloons. For example, the central control system **200** may input state information that is received from balloons **206**A to **206**I to an energy function, which may effectively compare the current topology of the network to a desired topology, and provide a vector indicating a direction of movement (if any) for each balloon, such that the balloons can move towards the desired topology. Further, the central control system **200** may use altitudinal wind data to determine respective altitude adjustments that may be initiated to achieve the movement towards the desired topology. The central control system **200** may provide and/or support other station-keeping functions as well.

FIG. **2** shows a distributed arrangement that provides centralized control, with regional control systems **202**A to **202**C coordinating communications between a central control system **200** and a balloon network **204**. Such an arrangement may be useful to provide centralized control for a balloon network that covers a large geographic area. In some embodiments, a distributed arrangement may even support a global balloon network that provides coverage everywhere on earth. Of course, a distributed-control arrangement may be useful in other scenarios as well.

Further, it should be understood that other control-system arrangements are also possible. For instance, some implementations may involve a centralized control system with additional layers (e.g., sub-region systems within the regional control systems, and so on). Alternatively, control functions may be provided by a single, centralized, control system, which communicates directly with one or more downlink balloons.

In some embodiments, control and coordination of a balloon network may be shared by a ground-based control system and a balloon network to varying degrees, depending upon the implementation. In fact, in some embodiments, there may be no ground-based control systems. In such an embodiment, all network control and coordination functions may be implemented by the balloon network itself (e.g., by processing systems situated on payloads of one more balloons in the network **204**). For example, certain balloons may be configured to provide the same or similar functions as central control system **200** and/or regional control systems **202**A to **202**C. Other examples are also possible.

Furthermore, control and/or coordination of a balloon network may be de-centralized. For example, each balloon may relay state information to, and receive state information from, some or all nearby balloons. Further, each balloon may relay state information that it receives from a nearby balloon to some or all nearby balloons. When all balloons do so, each balloon may be able to individually determine the state of the network. Alternatively, certain balloons may be designated to aggregate state information for a given portion of the network. These balloons may then coordinate with one another to determine the overall state of the network.

Further, in some aspects, control of a balloon network may be partially or entirely localized, such that it is not dependent on the overall state of the network. For example, individual balloons may implement balloon-positioning functions that only consider nearby balloons. In particular, each balloon may determine how to move (and/or whether to move) based on its own state and the states of nearby balloons. The balloons may use an optimization routine (e.g., an energy function) to determine respective positions to, for example, maintain and/or move to a desired position with respect to the nearby balloons, without necessarily considering the desired topology of the network as a whole. However, when each balloon implements such an position determination routine, the balloon network as a whole may maintain and/or move towards the desired spatial distribution (topology).

2c) Example Balloon Configuration

Various types of balloon systems may be incorporated in an example balloon network. As noted above, an example embodiment may utilize high-altitude balloons, which could typically operate in an altitude range between 18 km and 25 km. FIG. **3** illustrates a high-altitude balloon **300**, according to an example embodiment. As shown, the balloon **300** includes an envelope **302**, a skirt **304**, and a payload **306**, which is shown as a block diagram.

The envelope **302** and skirt **304** may take various forms, which may be currently well-known or yet to be developed. For instance, the envelope **302** and/or skirt **304** may be made of metallic and/or polymeric materials including metalized Mylar or BoPet. Additionally or alternatively, some or all of the envelope **302** and/or skirt **304** may be constructed from a highly-flexible latex material or a rubber material such as chloroprene. Other materials are also possible. The envelope **302** may be filled with a gas suitable to allow the balloon **300** to reach desired altitudes in the Earth's atmosphere. Thus, the envelope **302** may be filled with a relatively low-density gas, as compared to atmospheric mixtures of predominantly molecular nitrogen and molecular oxygen, to allow the balloon **300** to be buoyant in the Earth's atmosphere and reach desired altitudes. Various different gaseous materials with suitable properties may be used, such as helium and/or hydrogen. Other examples of gaseous materials (including mixtures) are possible as well.

The payload **306** of balloon **300** may include a computer system **312** having a processor **313** and on-board data storage, such as memory **314**. The memory **314** may take the form of or include a non-transitory computer-readable medium. The non-transitory computer-readable medium may have instructions stored thereon, which can be accessed and executed by the processor **313** in order to carry out the balloon functions described herein. Thus, processor **313**, in conjunction with instructions stored in memory **314**, and/or other components, may function as a controller of balloon **300**.

The payload **306** of balloon **300** may also include various other types of equipment and systems to provide a number of different functions. For example, payload **306** may include an optical communication system **316**, which may transmit optical signals via an ultra-bright LED system, and which may receive optical signals via an optical-communication receiver (e.g., a photodiode receiver system). Further, payload **306** may include an RF communication system **318**, which may transmit and/or receive RF communications via an antenna system.

The payload **306** may also include a power supply **326** to supply power to the various components of balloon **300**. The power supply **326** could include a rechargeable battery or other energy storage devices. The balloon **300** may include a solar power generation system **327**. The solar power generation system **327** may include solar panels and could be used to generate power that charges and/or is distributed by the power supply **326**. In other embodiments, the power supply **326** may additionally or alternatively represent other means for producing power.

The payload **306** may additionally include a positioning system **324**. The positioning system **324** could include, for example, a global positioning system (GPS), an inertial navigation system, and/or a star-tracking system. The positioning system **324** may additionally or alternatively include various motion sensors (e.g., accelerometers, magnetometers, gyroscopes, and/or compasses). The positioning system **324** may additionally or alternatively include one or more video and/or still cameras, and/or various sensors for capturing environmental data indicative of the geospatial position of the balloon **300**, which information may be used by the computer system **312** to determine the location of the balloon **300**.

Some or all of the components and systems within payload **306** may be implemented in a radiosonde or other probe, which may be operable to measure environmental parameters, such as pressure, altitude, geographical position (latitude and longitude), temperature, relative humidity, and/or wind speed and/or wind direction, among other information.

As noted, balloon **300** may include an ultra-bright LED system for free-space optical communication with other balloons. As such, optical communication system **316** may be configured to transmit a free-space optical signal by modulating the ultra-bright LED system. The optical communication system **316** may be implemented with mechanical systems and/or with hardware, firmware, and/or software. Generally, the manner in which an optical communication system is implemented may vary, depending upon the particular application. The optical communication system **316** and other associated components are described in further detail below.

In a further aspect, balloon **300** may be configured for altitude control. For instance, balloon **300** may include a variable buoyancy system, which is configured to change the altitude of the balloon **300** by adjusting the volume and/or density of the gas in the balloon **300**. A variable buoyancy system may take various forms, and may generally be any system that can change the volume and/or density of gas in the envelope **302**.

In an example embodiment, a variable buoyancy system may include a bladder **310** that is located inside of envelope **302**. The bladder **310** could be an elastic chamber configured to hold liquid and/or gas. Alternatively, the bladder **310** need not be inside the envelope **302**. For instance, the bladder **310** could be a rigid container holding liquefied and/or gaseous material that is pressurized in excess of the pressure outside the bladder **310**. The buoyancy of the balloon **300** may therefore be adjusted by changing the density and/or volume of the gas in bladder **310**. To change the density in bladder **310**, balloon **300** may be configured with systems and/or mechanisms for heating and/or cooling the gas in bladder **310**. Further, to change the volume, balloon **300** may include pumps or other features for adding gas to and/or removing gas from bladder **310**. Additionally or alternatively, to change the volume of bladder **310**, balloon **300** may include release valves or other features that are controllable to allow gas to escape from bladder **310**. Multiple bladders **310** could be implemented within the scope of this disclosure. For instance, multiple bladders could be used to improve balloon stability.

In an example embodiment, the envelope **302** could be filled with helium, hydrogen or other gaseous material with density less than typical atmospheric gas (i.e., "lighter-than-air" gasses). The envelope **302** could thus have an associated upward buoyancy force based on its displacement. In such an embodiment, air in the bladder **310** could be considered a ballast tank that may have an associated downward ballast force. In another example embodiment, the amount of air in the bladder **310** could be changed by pumping air (e.g., with an air compressor) into and out of the bladder **310**. By adjusting the amount of air in the bladder **310**, the ballast force may be controlled. In some embodiments, the ballast force may be used, in part, to counteract the buoyancy force and/or to provide altitude stability.

In other embodiments, the envelope **302** could be substantially rigid and include an enclosed volume. Air could be evacuated from envelope **302** while the enclosed volume is substantially maintained. In other words, at least a partial vacuum could be created and maintained within the enclosed volume. Thus, the envelope **302** and the enclosed volume could become lighter than air and provide a buoyancy force. In yet other embodiments, air or another material could be controllably introduced into the partial vacuum of the enclosed volume in an effort to adjust the overall buoyancy force and/or to provide altitude control.

In another embodiment, a portion of the envelope **302** could be a first color (e.g., black) and/or formed of a first material different from the rest of envelope **302**, which may have a second color (e.g., white) and/or a second material. For instance, the first color and/or first material could be configured to absorb a relatively larger amount of solar energy than the second color and/or second material. Thus, rotating the balloon such that the first material is facing the sun may act to heat the envelope **302** as well as the gas inside the envelope **302**. In this way, the buoyancy force of the envelope **302** may increase. By rotating the balloon such that the second material is facing the sun, the temperature of gas inside the envelope **302** may decrease. Accordingly, the buoyancy force may decrease. In this manner, the buoyancy force of the balloon could be adjusted by changing the temperature/volume of gas inside the envelope **302** using solar energy. In such embodiments, it is possible that a bladder **310** may not be a necessary element of balloon **300**. Thus, in various contemplated embodiments, altitude control of balloon **300** could be achieved, at least in part, by adjusting the rotation of the balloon with respect to the sun to selectively heat/cool the gas within the envelope **302** and thereby adjust the density of such gas.

Further, a balloon **306** may include a navigation system (not shown). The navigation system may implement positioning functions to maintain position within and/or move to a position in accordance with a desired spatial distribution of balloons (balloon network topology). In particular, the navigation system may use altitudinal wind data to determine altitudinal adjustments that result in the wind carrying the balloon in a desired direction and/or to a desired location. The altitude-control system may then make adjustments to the density of the balloon envelope **302** to effect the determined altitudinal adjustments and thereby cause the balloon **300** to move laterally to the desired direction and/or to the desired location. Additionally or alternatively, desired altitudinal adjustments may be computed by a ground-based or satellite-based control system and communicated to the balloon **300**. In other embodiments, specific balloons in a balloon network may be configured to compute altitudinal adjustments for other balloons and transmit the adjustment commands to those other balloons.

Several example implementations are described herein. It will be understood that there are many ways to implement the devices, systems, and methods disclosed herein. Accordingly, the following examples are not intended to limit the scope of the present disclosure.

3. Ground-Facing Antennas

FIG. **4**A illustrates an example high-altitude balloon **402** with a ground-facing antenna situated to illuminate a geographic region **406** at ground level. The balloon **402** can be similar to the balloon **300** described in connection with FIG. **3** and can include an RF communication system mounted to a payload for operating the ground-facing antenna, similar to the RF communication system **318** in the payload **306** of the balloon **300**. The ground-facing antenna emits radiation in an emission pattern **404** that causes signals at ground level to substantially span the geographic region **406** while the balloon is at altitude A_1. Similarly, FIG. **4**B illustrates the balloon **402** at altitude A_2 and illuminating the geographic region **406** by emitting radiation from the ground-facing antenna with an emission pattern **405** so as to substantially span the geographic region **406** at ground level. The emission pattern **404** used at altitude A_1 has a characteristic angular span θ_1, while the emission pattern **405** used at altitude A_1 has a characteristic angular span θ_2. While the antenna and its adjustable emission patterns **404**, **405** are described herein in connection with the high-altitude balloon **402** for purposes of convenience, it is specifically noted that such an antenna with adjustable emission pattern may be mounted to, and used in connection with, a variety of high altitude platforms, such as other lighter-than-air devices and the like.

As illustrated in FIGS. **4**A and **4**B, the angular span θ_1 can be larger than θ_2, such that the emission pattern **404** spans roughly the same area at ground level (i.e., the area of geographic region **406**) as the area spanned by emission pattern **405**, even while the first altitude A_1 is lower than the second altitude A_2. The balloon's antenna can be configured such that the emission patterns **404**, **405** (and respective angular spans θ_1, θ_2) at least approximately span the same ground level geographic region **406** regardless of the elevation of the balloon **402**. Thus, the balloon **402** can be configured to maintain communication with a substantially fixed geographic region (i.e., the region **406**) even as the balloon ascends and descends to various elevations.

Moreover, the more directed emission pattern **405** shown in FIG. **4**B, as indicated by the smaller angle θ_2, may have a greater directional gain. As such, the increased directional gain of emission pattern **405** may at least partially compensate for the greater distance between the balloon **402** and the ground level in FIG. **4**B (i.e., the altitude A_2). For example, the radiation at ground level in the geographic region **406** may have comparable intensity whether from the more broadly emission pattern **404** with the balloon **402** at altitude A_1 or from the more narrowly beamed emission patter **405** with the balloon **402** at altitude A_2. Generally, the intensity of radiation at ground level from emission pattern **405**, with angular span θ_2, may be greater than radiation that would be provided from the same altitude by emission pattern **404**, with angular span θ_1, and so the more directed emission pattern **405** thereby at least partially compensates for the altitude-dependent variations in radiation intensity at ground level.

In some examples, the first altitude A_1 may be near a low end of a desired stratospheric altitude for the high-altitude balloon **402** (e.g., 18 km), and the second altitude A_2 may be near a high end of a desired stratospheric altitude for the high altitude balloon **402** (e.g., 25 km). The angular span θ_1 of the emission patterns **404** can be approximately 90° (e.g., an approximately conical radiation pattern with a 45° half-width), and the angular span θ_2 of the emission pattern **405** can be approximately 70° (e.g., an approximately conical radiation pattern with a 36° half-width).

In a further example, the emission pattern can be adjusted to account for variations in ground-level elevation. For example, the balloon **402** can include an antenna with an emission pattern that is adjusted based on the altitude of the balloon **402**, relative to ground level immediately below the balloon **402**. In other words, the emission pattern can be adjusted based on the absolute altitude, relative to sea-level, such as detected by ambient pressure, and can additionally or alternatively be adjusted based on altitude, relative to ground. Thus, the balloon **402** may be configured to at least partially compensate for variations in relative altitude (e.g., due to the balloon passing over regions with variations in ground level altitude) in order to maintain an at least approximately constant geographic span and/or intensity level of radiation reaching ground level. In one example, the balloon **402** may traverse over a region with a series of ground elevation changes (e.g., hills, valleys, slopes, flat areas, mountains, etc.). The balloon **402** can dynamically adjust the radiation pattern of its ground-facing antenna to at least partially compensate for altitude-dependent variations in the radiation that reaches the ground from the balloon **402**. For example, the emission pattern may be relatively broad, similar to the emission pattern **404** with angular span θ_1 shown in FIG. **4**A, while over a high elevation region, and thus relatively low relative altitude. Similarly, the emission pattern may be relatively narrow, similar to the emission pattern **405** with angular span θ_2 shown in FIG. **4**B, while over a low elevation region, and thus relatively high relatively altitude.

In some examples, the relative altitude (i.e., distance from ground to balloon **402**) can be determined by predetermined ground-level elevation data in combination with position information (e.g., as determined by a GPS receiver or the like) and one or more altitude sensors on the balloon **402** (e.g., altimeters and/or pressure sensors and the like). Upon determining position information for the balloon, such as latitude and longitude coordinates, a mapping database can be accessed to determine a corresponding ground level elevation immediately below the balloon **402**. The ground-level elevation, which can be determined by a computer system on the balloon **402** (e.g., similar to the computer system **312** in the payload **306** of the balloon **300**) and/or by a remote server in communication with the balloon **402**, can then be combined with the altitude of the balloon **402** as determined via the on-board sensors to determine the distance from the balloon **402** to the ground (i.e., the relative altitude). In other examples, the balloon **402** may include sensors configured to directly sense and/or determine the relative altitude of the balloon **402**, such as downward facing radar and the like.

In a further example, the emission pattern can be adjusted to account for influences on the radiation from the balloon due to atmospheric effects, such as weather patterns in the troposphere. As an example, particular portions of the spectrum may be sensitive to inclement weather due to increases in radiation attenuating water vapor and/or droplets in the troposphere, for example. To achieve a desired radiation intensity at ground level (e.g., a minimum signal to noise ratio), the emission pattern may be narrowed in response to detecting certain weather patterns. In other words, the radiation pattern may be narrowed so as to increase the directional gain in the illuminated region at ground level, to account for radiation attenuating weather patterns in the atmosphere between ground level and the high-altitude balloon **402**. In some examples, such weather-related effects can be accounted for by systems that dynamically detect weather patterns and communicate accordingly with the balloon **402**. In other examples, such weather-related effects can be detected directly via sensors on the balloon **402**. Additionally or alternatively, such weather conditions (and/or other signal degrading phenomena) can be inferred through detection of degradation in signal strength at stations at ground-level. In other words, the signal to noise ratio (or other measure of signal strength) at ground-based stations can be used as feedback information to dynamically adjust the emission pattern, and thus the direction gain, of the ground-facing antenna on the balloon **402**.

Some embodiments of the present disclosure accordingly provide for ground-facing antennas with emission pattern that change based on altitude. The ground-facing antennas can change emission pattern in a manner that at least partially compensates for variations in the radiation at ground level that would otherwise occur due to altitude changes. Such altitude-based compensations in emission pattern can be performed by adjusting the distance between a radiating element and a reflector in the ground-facing antenna. Examples of antennas with adjustable separation distances between radiator and reflectors are described next.

As a preliminary matter, it is noted that the discussion herein generally refers to transmission of radio signals according to adjustable emission patterns (or radiation patterns) to illuminate geographic regions (e.g., the geographic region **406** at ground level illuminated by the emission patterns **404**, **405**). However, due to the general reciprocity between emission and reception of radio signals in antenna theory and design, it is recognized that the discussion throughout generally has equal application to the reception of signals from a particular ground-level geographic region. That is, the antennas with altitude-dependent adjustable radiation patterns may be used additionally or alternatively to receive signals arriving from the radiation patterns (e.g., from within the geographic region **406** at ground level). In such an example, adjusting the radiation pattern allows the receiving antenna (mounted to the high-altitude balloon) to at least partially compensate for the change in sensitivity that naturally accompanies changes in altitude. For example, such antennas may increase their directional gain at higher altitudes, as shown in FIGS. **4**A and **4**B.

FIG. **4**C illustrates a ground-facing antenna **408** with a radiator **420**, a reflector **410**, and a linkage **440** that controls the separation distance d_1 between the radiator **420** and reflector **410** to provide an emission pattern with angular span θ_1. FIG. **4**D illustrates the ground-facing antenna **408** of FIG. **4**C, but with a greater separation distance d_2 between the radiator **420** and reflector **410**, which results in a more directed emission pattern, as indicated by the angular span θ_2. The ground-facing antenna **408** shown in FIGS. **4**C and **4**D can be mounted to a payload of a high-altitude balloon to radiate downward while the balloon is aloft, similar to the balloon **402** described in connection with FIGS. **4**A and **4**B with a payload-mounted ground-facing antenna. In an example where the antenna **408** is mounted to the payload of the balloon **402**, the configuration of the antenna **408** in FIG. **4**C, with separation distance d_1 and emission pattern angular span θ_1, can be used to provide the emission pattern **404** with the balloon at altitude A_1 (FIG. **4**A). Similarly, the configuration of the antenna **408** in FIG. **4**D, with separation distance d_2 and emission pattern angular span θ_2, can be used to provide the emission pattern **405** with the balloon at altitude A_2 (FIG. **4**B).

As shown in FIG. **4**C, a transmitter **430** is connected to the radiator **420** via a transmission line **432**. The transmitter **430** can be included in, or in communication with, a computer system and/or RF communication system within the payload of a balloon to which the antenna **408** is mounted, similar to the computer system **312** and RF communication system **318** described in connection with the balloon **300** in FIG. **3**. The transmitter **430** can thus provide input signals to the radiator **420** to cause the radiator **420** to emit corresponding radiation **422**, **424**, which radiation is then reflected by the reflector **410**. Although it is noted that in some embodiments in which the antenna **408** is used to receive incoming radiation, the transmitter **430** may be replaced by a receiver configured to receive information based on harvested radio energy radiating through free space to excite the antenna element **420**.

The radiator **420** can be any type of directional or non-directional radiating element suitable for emitting signals according to inputs, such as a horn feed antenna, a bi-pole antenna, etc. The reflector **410** can be a solid or non-solid (e.g., mesh), and may be spherically invariant dish (e.g., the reflective surface of the dish may be equidistant from a common point, or spherical center). In some examples, the reflector **410** may be a cylindrically symmetric dish with a concave curvature defined by a parabolic curvature. In some examples, moreover, the reflector **410** may be a single flat, planar reflective surface, or may be formed of multiple flat panels which may be co-planar or may be combined to create a general concave or convex curvature so as to direct the radiation **422**, **424** emitted from the radiator **420** according to a desired pattern.

As shown in FIG. **4**C, the radiator **420** is separated from the reflector **410** by a distance d_1. The transmitter **430** provides input signals to the radiator **420** to cause the radiator **420** to emit radiation **422** toward the reflector **410**. The radiation **422** from the radiator **420** is then reflected by the reflector **410** and directed in an emission pattern with angular span θ_1 (e.g., a conical radiation pattern with apex approximately located at the antenna **408** and opening angle θ_1). The angular span of the resulting emission pattern is determined, at least in part, by the separation distance between the radiator **420** and the reflector **410**. Assuming symmetric reflections about incident angles for radiation reflected from the reflector **410**, ray tracing radiation from the radiator **420** to the reflector **410** and then outward away from the reflector **410** shows that the angular span of radiation reflected from the reflector **410** is increased at lower separation distances d_1, and vice versa. Thus, the configuration of the antenna **408** in FIG. **4**D, with separation distance $d_2>d_1$ by difference Δd results in an emission pattern with a decreased angular span θ_2.

A linkage **440** controls the separation distance between the radiator **420** and the reflector **410**. The linkage **440** may be a structure that is connected to one or both of the radiator **420** or the reflector **410** and includes adjustable elements, telescoping components, pulleys, wheels, gears, stepper motors, etc., to cause the radiator **410** to move with respect to the reflector **420** or vice versa, and thereby control the separation distance between the two. The linkage **440** may include one or more support arms that connect to the radiator **410** to suspend the radiator **410** above the reflector **420**. In some examples, the reflector **410** may be mounted to a fixed portion of the balloon's payload, while the radiator **410** is able to move toward and away from the reflector **420** via the linkage **440**. In other examples, the radiator **410** may be mounted to a fixed portion of the balloon's payload, while the reflector **420** is able to move toward and away from the radiator **410** via the linkage **440**. Other examples are also possible to allow the linkage **440** to adjust the separation distance between the radiator **410** and the reflector **420**. Thus, FIG. **4**D may illustrate the linkage **430** in an extended state in which the separation distance d_2 is increased by difference Δd, relative to a compressed state illustrated in FIG. **4**C in which the linkage **430** provides a separation distance d_1.

The configuration of the radiator **410** and reflector **420** in FIGS. **4**C and **4**D are provided for purposes of illustration and example only, and not limitation. In other examples, alternative arrangements may be used, such as arrangements with multiple reflection points (e.g., antenna designs incorporating sub-reflectors), and combinations of convex, concave, and/or flat reflectors to provide variable focal lengths and thus variable radiation patterns.

3a) Altitude-Adjustable Linkages

FIG. **5**A is a simplified block diagram of an antenna **500** with a dynamically adjustable emission pattern. The antenna **500** is configured to mounted to a payload of a high-altitude balloon (or another high altitude platform) in a ground-facing orientation, similar to the antenna described in connection with FIGS. **4**A-**4**D. The antenna **500** includes a radiator **520**, a reflector **510**, and a linkage **540** that controls the separation distance d_{SEP} between the radiator **520** and the reflector **510**. The linkage **540** is configured to adjust the separation distance d_{SEP} according to instructions from a controller **550**.

The controller **550** can include a combination of hardware and/or software implemented modules included in the payload of the balloon to which the antenna **500** is mounted. The controller **550** can be configured to determine the altitude of the antenna **500**, such as via altitude determination logic **552**, which may include computer-readable instructions for being executed by a processor. The controller **550** may thus include (or be included in) a computer system similar to the computer system **312** in the payload **306** of the balloon **300** described in connection with FIG. **3**. To determine the altitude of the antenna **500**, the controller **550** receives sensor inputs **554**. The sensor inputs **554** can include information from pressure and/or temperature sensors (e.g., an altimeter). The sensor inputs **554** can also include information from geo-location navigation and/or communication systems, such as position information derived from time-of-flight measurements to/from reference objects, (e.g., GPS satellites, other high-altitude balloons, ground-based stations, etc.).

In operation, the sensor inputs **554** provide inputs to the controller **550**, which inputs are indicative of the altitude of the balloon to which the antenna **500** is mounted. The controller **550** analyzes the information from the sensor inputs **554** to determine the altitude of the balloon (e.g., via the altitude determination logic **552**). For example, measurements of pressure and/or temperature, and/or time-of-flight delays to reference objects can be analyzed by the controller **550** (via the altitude determination logic **552**) to determine the altitude of the balloon. The controller **550** can then instruct the linkage **540** to adjust the separation distance d_{SEP} between the radiator **520** and the reflector **510**, which adjustment results in a change in the emission pattern of the antenna **500**. In some examples, the controller **550** operates to provide instructions to the linkage **540** that cause the separation distance d_{SEP} to increase in response to a decreased altitude (as determined by the altitude determining logic **552**). Additionally, the controller **550** can provide instructions to cause the separation distance d_{SEP} to decrease in response to an increased altitude (as determined by the altitude determining logic **552**).

Moreover, the controller **550** can be configured to additionally or alternatively detect other inputs and cause the separation distance d_{SEP} to be adjusted accordingly. For example, the controller **550** can instruct the linkage **540** to adjust the separation distance based on variations in relative altitude (e.g., distance from ground level to the antenna), variations in weather conditions (e.g., estimates of tropospheric water vapor and/or water droplet density), and/or other variations in received signal conditions at ground-level signal (e.g., as indicated by feedback on received signal strength at ground stations), as described in connection with FIGS. **4**A and **4**B above.

The linkage **540** can include one or more components configured to adjust mechanical length in response to suitable instructions from the controller **550**. For example, the linkage **540** may include telescoping components, elastic components, other moveable components, etc., and associated motors, gears, pulleys, etc., configured to modify the relative position(s) of such moveable components according to the instructions from the controller **550**. Moreover, the linkage **540** may include one or more devices configured to provide position feedback information on the state of the linkage **540** (e.g., the relative positions of the various moveable components). The feedback devices can be, for example one or more encoders and/or other position sensor(s). Such feedback devices can then provide feedback position data to the controller **550**, which can use the data to estimate the present value of d_{SEP}, and then further refine instructions to the linkage on whether and how to adjust the linkage **540**. Thus, the instructions to the linkage **540** from the controller **550** may be based on one or both of linkage-position feedback data or altitude-indicative sensor data (**554**).

FIG. **5**B is a simplified block diagram of another antenna **501** with a dynamically adjustable emission pattern. Whereas the antenna **500** described in connection with FIG. **5**A actively determines the altitude of the antenna, and then causes the separation distance d_{SEP} to adjust (e.g., by sending suitable electronic signals), the antenna **501** is configured to passively adjust the separation distance d_{SEP} between the radiator **520** and the reflector **510** in response to changes in atmospheric pressure.

In the antenna **501**, the radiator **520** is mounted to a supporting structure **545**, which may be one or more support arms that suspend the radiator **520** below the reflector **510**. For example, the supporting structure **545** may be an arrangement of support arms situated in a plane approximately parallel to the reflector **510**. The supporting structure **545** can then be connected to anchor points **560***a-b* via respective pressure-sensitive vessels **540***a-b*. The anchor points **560***a-b* can be structural points connected to the payload of the balloon to which the antenna **501** is mounted, and such anchor points can be substantially fixed in position with respect to the reflector **510**, which is also mounted to the payload of the balloon.

The pressure-sensitive vessels **540***a-b* can be containers with flexible sidewalls that allow the vessels **540***a-b* to expand and contract along their length. For example, the vessels **540***a-b* can have end caps each extending perpendicular to their respective lengths, which join to the flexible sidewalls. In FIG. **5**B, the supporting structure **545** and anchor points **560***a-b* can be connected to opposing end caps of the vessels **540***a-b*, such that the flexible sidewalls extend between the two. By orienting the vessels **540***a-b* with adjustable lengths between the supporting structure **545** and the anchor points **560***a-b*, adjusting the length of the pressure-sensitive vessels **540***a-b* causes a corresponding adjustment in the separation distance d_{SEP} between the radiator **520** and the reflector **510**.

The pressure-sensitive vessels **540***a-b* adjust their lengths in response to changes in external pressure (i.e., atmospheric pressure). The pressure-sensitive vessels **540***a-b* may include an internal chamber that is substantially evacuated (e.g., near vacuum pressure). As such, the flexible side walls can have sufficient structural rigidity to prevent the vessel from collapsing on itself, even when the chamber is substantially evacuated. The flexible side walls may be formed, for example, of corrugated metal that resists compression, but deforms (e.g., bends) to allow the vessel to contract in length. The amount of compression (and thus mechanical deformation) can thus depend on the amount of external force urging the vessel to a decreased volume, which force can be supplied by ambient pressure. For the vessels **540***a-b*, which are substantially flexible only along their length, the expansion/contraction in volume is an expansion/contraction in length, and therefore separation distance d_{SEP} between the radiator **520** and the reflector **510**. In some examples, another semi-rigid material may be employed additionally or alternatively to corrugated metal to allow the vessel to contract systematically in response to changes in ambient pressure.

By using a pressure-sensitive vessel that is substantially evacuated (e.g., by providing pressure near vacuum in the internal chamber), the vessels **540***a-b* desirably exhibit greater insensitivity to temperature variations than comparable vessels filled with fluid, such as gas. For example, at high altitudes, a high altitude platform may alternate between receiving large exposures of solar radiation and receiving virtually no radiation, depending on night time or day time. During periods in which the high altitude platform is exposed to the solar radiation (e.g., during daytime hours for a geostationary platform), any gas trapped within the pressure-sensitive vessel would be heated, and undergo expansion. Similarly, during periods lacking exposure to solar radiation (e.g., during nighttime hours for a geostationary platform), such gas would be cooled, and undergo contraction. Such temperature-dependent expansion and contraction of gas within the pressure-sensitive vessels would be substantially independent of variations in altitude and may therefore have to be separately compensated for. Other sources of thermal variations are also possible, such as due to operation of electronics on the payload of the high altitude platform, and other sources. However, evacuating the internal chambers of the pressure-sensitive vessels substantially eliminates temperature-dependent pressure fluctuations of the internal chamber of such vessels.

Alternatively, the internal chamber may be filled with a fluid, such as a gas, and the internal chamber may be in fluid connection with at least one of the end caps of the vessel **540***a*, such that the pressure within the internal chamber at least approximately balances the external pressure on the pressure-sensitive vessel **540***a*. The internal chamber may be sealed, such that the pressure within the internal chamber is inversely proportionate to the volume of the vessel **540***a*. Thus, at low ambient pressure, the pressure-sensitive vessel expands to a large volume to allow the pressure in the internal chamber to at least approximately balance the atmospheric pressure. Similarly, at high ambient pressure, the pressure-sensitive vessel contracts to a smaller volume. As noted above, gas within the vessels **540***a-b*, can cause the vessels to expand and contract with dependence on temperature variations separate from altitude-dependent temperature variations, so the separation distance d_{SEP} may then have a separate temperature-based compensation system.

The antenna **501** passively adjusts d_{SEP} based on altitude, because the pressure of the stratosphere generally decreases with altitude, and therefore serves as a proxy for altitude sensitivity. As a result, the antenna **501** has a greater separation distance (and therefore narrower radiation pattern) at greater altitudes where the ambient pressure is lower and the pressure-sensitive vessels **540***a-b* therefore expand. Similarly, the antenna **501** has a lesser separation distance (and therefore broader radiation pattern) at lesser altitudes where the ambient pressure is greater and the pressure-sensitive vessels **540***a-b* therefore contract.

FIG. **5**C is a simplified block diagram of another antenna **502** with a dynamically adjustable emission pattern. The antenna **502** is similar to the antenna **501**, except that the radiator **520** is disposed so as to be substantially fixed with respect to the payload of the balloon to which the antenna **502** is mounted, and the reflector **510** is suspended to move with respect to the radiator **520**. The reflector **510** can be connected to a supporting structure **546**, which supporting structure is then connected to one or more anchor points **562***a-b* via pressure-sensitive vessels **542***a-b*. The anchor points **562***a-b* can be substantially fixed with respect to the payload of the balloon to which the antenna **502** is mounted (and also with respect to the radiator **520**). The separation distance d_{SEP} between the radiator **520** and the reflector **510** is thus automatically adjusted in response to changes in ambient pressure due to expansion/contraction of the pressure-sensitive vessels **542***a-b*, which expansion/contraction moves the supporting structure **546**, and thus the reflector **510**, with respect to the anchor points **562***a-b*. As compared to the antenna **501** in FIG. **5**B, the configuration of the antenna **502** shown in FIG. **5**C may allow for the radiator **520** to be fixed structurally with respect to the payload of the balloon. As a result, the transmission line for signals feeding the radiator **520** can be connected along a fixed, non-moveable structural element.

In some examples, the pressure-sensitive vessel(s) **540***a-b*, **542***a-b* can each be a generally cylindrical container with corrugated (e.g., ribbed) metallic sidewalls, similar to a bellows or an aneroid employed in barometric sensors. While FIGS. **5**B and **5**C illustrate multiple pressure-sensitive vessels connected to the radiator **520** (via the supporting structure **545**) and/or the reflector **520** (via the supporting structure **546**), some embodiments of adjustable linkages may include just one pressure-sensitive vessel or more than two pressure-sensitive vessels.

Examples of pressure-sensitive vessels configured as aneroids (e.g., vessels with at least one flexible surface capable of contraction or expansion in response to are described below in connection with FIG. **6**. However, some examples may additionally or alternatively include a hollow tube that is arranged to coil/uncoil in response to ambient pressure changes (e.g., a Bourdon tube, etc.) and/or other systems or devices that mechanically respond to variations in ambient pressure. An antenna may be configured to modify its beaming pattern based on the mechanical response of such systems or devices.

Moreover, while some embodiments of the present disclosure may apply to antennas with at least one radiator and at least one reflector, some embodiments may apply to antennas with a variety of other form factors. For example, some embodiments may apply to antennas with multiple radiators (e.g., driven elements) and/or multiple reflectors (e.g., passive elements). In some embodiments a Yagi-type antenna (and/or other antennas including dipole elements and/or parasitic elements) may be configured such that one or more driven elements and/or one or more passive elements (e.g., directors, reflectors, etc.) have spatial separations that depend, at least in part, on a pressure-sensitive vessel (and/or other systems or devices that mechanically respond to variations in ambient pressure). The pressure-dependent relative spacing between the driven elements and/or passive elements may then cause the directivity (e.g., beaming pattern) of such an antenna to be modified based on antenna altitude. Thus, in some examples, a Yagi type antenna (or another antenna with multiple driven elements and/or passive elements) can have relative spacing between elements adjusted in an altitude-dependent manner such that the resulting radiation pattern is adjusted in an altitude-dependent manner (e.g., so as to at least partially compensate for ground level variations in geographical boundaries and/or intensity of the radiation pattern).

3b) Pressure-Sensitive Vessel

FIG. **6**A shows a pressure-sensitive vessel **600** in an expanded state. FIG. **6**B shows the pressure-sensitive vessel **600** in a contracted state. The pressure-sensitive vessel **600** includes a first end cap **602** and a second end cap **604**. A flexible sidewall **610** connects the first and second end caps **602**, **604** so as to enclose an inner chamber. The inner chamber can be substantially evacuated, and can have a pressure near vacuum. The flexible sidewall **610** includes a plurality of alternating ridges **614***a-c* and grooves **612***a-b* along a direction transverse to the length of the vessel **600**, which extends between the two end caps **602**, **604**. The alternating ridges **614***a-c* and grooves **612***a-b* combine to create a corrugated structure that allows the flexible sidewall **610** to expand/contract along the length of the vessel **600**. The flexible sidewall **610** and/or the end caps **602**, **604** can be formed of a rigid metallic material, such as aluminum, for example. In addition, joints and/or seams in the pressure-sensitive vessel can be sealed with flexible sealants and/or films, such as polymeric materials and the like in order to seal the inner chamber enclosed by the end caps **602**, **604** and the flexible sidewall **610**.

For example, the vessel **600** can expand/contract by flexing the joints along the corrugated ridges **614***a-c* and grooves **612***a-b* of the flexible sidewall **610**. In the expanded state, shown in FIG. **6**B, the length of the pressure-sensitive vessel **600** (e.g., the distance between the opposing end caps **602**, **604**) is L_{EXP}. In FIG. **6**B, in the contracted state, the length of the pressure-sensitive vessel **600** is L_{COMP}. By forming the pressure-sensitive vessel **600** of rigid materials configured to expand/contract in one dimension (via the flexible sidewall **610**), the pressure-sensitive vessel **600** harnesses pressure-sensitive expansion/contraction of the volume of the vessel **600** to cause the vessel **600** to change length.

In FIG. **6**A, the pressure-sensitive vessel **600** can be in a low ambient pressure environment, such as encountered at high altitudes in the stratosphere (e.g., approximately 25 km). The low ambient pressure creates relatively little force on the external walls of the pressure-sensitive vessel **600** and the flexible sidewall **610** expands to cause the vessel **600** to have length L_{EXP}. In FIG. **6**B, the pressure-sensitive vessel **600** can be in a higher ambient pressure environment, such as encountered at low altitudes in the stratosphere (e.g., approximately 18 km). The higher ambient pressure creates a relatively greater force on the external walls of the pressure-sensitive vessel **600** and the flexible sidewall **610** contracts to cause the vessel **600** to have length L_{COMP}.

Generally, the pressure-sensitive vessel **600** can include an internal chamber that is at a low pressure so that gas remaining in the chamber exerts less pressure than the atmosphere on the sidewalls. For example, the internal chamber can be at a vacuum or near vacuum pressure. In operation, when air pressure outside the chamber increases or decreases, the flexible sidewall **610** allows the aneroid (or other vessel) to contract or expand, respectively. In some embodiments, the flexible sidewall **610** acts as a spring to prevent the aneroid from collapsing. As such, suitable materials for this flexible surface include aluminum, stainless steel, brass, copper, Monel, and/or bronze. Other metals or plastics that maintain their spring rate with varied temperatures and multiple expansion and contraction cycles are also contemplated herein. In some embodiments, the aneroid may take the form of: a chamber with a bottom surface, a top surface and at least one collapsible sidewall or other flexible surface, a bellows, a capsule with a flexible diaphragm, and/or a stacked pile of pressure capsules with corrugated diaphragms. The foregoing list is not intended to be exhaustive and is provided merely by way of example.

3c) Flat Reflector Antennas

FIG. **7**A is a simplified diagram of an antenna **700** with a flat reflector **708**. The antenna **700** shown in FIG. **7**A can be configured to be mounted to a payload of a high-altitude balloon so as to be ground-facing, similar to the antennas described above in connection with FIG. **4-5**. A radiating element **702** is situated under the flat reflector **708**, and radiates according to input signals (e.g., from a transmitter). The radiating element **702** and reflector **708** can be similar to a patch antenna in some examples. In some examples, the radiating element can be a planar conductive component. The radiating element may be approximately 50 millimeters by 50 millimeters or may have other dimensions, including non-square dimensions (e.g., rectangular, etc.). The reflector **708** can be a planar conductive component plane parallel to the radiating element **702**. The reflector may be approximately 300 millimeters by 300 millimeters or may have other dimensions, including non-square dimensions (e.g., rectangular, etc.). A support arm **704** suspends the radiating element **702** with respect to the reflector **708**, and can also be used to convey transmission signals to the radiating element **702**. As shown in FIG. 7A, the radiating element **702** and/or reflector **708** may be rectangular in shape, and may even be square, for example.

An adjustable linkage **706** connects to the supporting arm and is configured to adjust the separation distance d_{SEP} between the radiating element **702** and the reflector **708** according to the altitude of the antenna **700**. The linkage **706** may be an active linkage with moveable components that are operated to adjust the separation distance based on a determined altitude of the antenna, similar to the active adjustable linkages described in connection with FIG. **5**A. Additionally or alternatively, the linkage **706** may be a passive linkage that includes one or more pressure-sensitive vessels connected so as to adjust the separation distance d_{SEP} in response to changes in ambient pressure, similar to the passive adjustable linkages described in connection with FIGS. **5**B and **5**C.

FIG. **7**B is a simplified diagram of another antenna **710** with a flat reflector **718**. The antenna **710** shown in FIG. **7**B can be configured to be mounted to a payload of a high-altitude balloon so as to be ground-facing, similar to the antennas described above in connection with FIG. **4-5**. A radiating element **712** is situated under the flat reflector **718**, and radiates according to input signals (e.g., from a transmitter). The radiating element **712** and reflector **718** can be similar to a patch antenna in some examples. In some examples, the radiating element can be a planar conductive component with an approximate area of 50 millimeters squared. The reflector **718** can be a planar conductive component plane parallel to the radiating element **712** and with an approximate area of 300 millimeters squared. A support arm **714** suspends the radiating element **712** with respect to the reflector **718**, and can also be used to convey transmission signals to the radiating element **712**. As shown in FIG. **7**B, the radiating element **712** and/or reflector **718** may have rounded edges, and may even be circular, for example.

An adjustable linkage **716** connects to the supporting arm and is configured to adjust the separation distance d_{SEP} between the radiating element **712** and the reflector **718** according to the altitude of the antenna **710**. The linkage **716** may be an active linkage with moveable components that are operated to adjust the separation distance based on a determined altitude of the antenna, similar to the active adjustable linkages described in connection with FIG. **5**A. Additionally or alternatively, the linkage **716** may be a passive linkage that includes one or more pressure-sensitive vessels connected so as to adjust the separation distance d_{SEP} in response to changes in ambient pressure, similar to the passive adjustable linkages described in connection with FIGS. **5**B and **5**C

4. Example Methods

FIG. **8**A is a flowchart of a process **800** for dynamically adjusting an antenna emission pattern according to an example embodiment. The process **800** illustrated in FIG. **8**A may be implemented by any of the ground-facing balloon-mounted antennas described herein alone or in combination with hardware and/or software implemented functional modules. At block **802**, radiation is emitted from a ground-facing antenna mounted to a high-altitude balloon. For example, radiation may be emitted from the antenna **408** so as to illuminate a geographic region at ground level, as described in connection with FIG. **4**. At block **804**, the emission pattern of the antenna is adjusted in response to a change in altitude of the antenna. For example, as described in connection with FIG. **4**, the emission pattern of antenna **408** can change from a broad pattern with angular span θ_1 while at altitude A_1 to a more directed pattern with angular span θ_2 upon reaching altitude A_2. At block **806**, the antenna emits radiation according to the adjusted emission pattern while at the new altitude. As indicated by the dashed arrow, the process **800** can optionally be repeated to cause the emission pattern to be intermittently (or perhaps even continuously) updated according to the then present altitude of the antenna.

Moreover, at block **804**, the emission pattern can additionally or alternatively be adjusted in response to a change in other aspects influencing signal propagation between ground level and an antenna at high altitude. For example, the emission pattern can be adjusted based on variations in relative altitude (e.g., distance from ground level to the antenna), variations in weather conditions (e.g., estimates of tropospheric water vapor and/or water droplet density), and/or other variations in received signal conditions at ground-level signal (e.g., as indicated by feedback on received signal strength at ground stations), as described in connection with FIGS. **4**A and **4**B above.

FIG. **8**B is a flowchart of a process **810** for dynamically adjusting an antenna emission pattern according to an example embodiment. The process **810** illustrated in FIG. **8**B may be implemented by any of the ground-facing balloon-mounted antennas described herein alone or in combination with hardware and/or software implemented functional modules. At block **812**, radiation is emitted from a ground-facing antenna mounted to a high-altitude balloon. For example, radiation may be emitted from the antenna **408** so as to illuminate a geographic region at ground level, as described in connection with FIG. **4**. At block **814**, the antenna components and/or associated control systems determine whether the antenna have increased in altitude. If the altitude is increased, the emission pattern of the antenna is adjusted by increasing the separation distance between the reflector and the radiator of the antenna (**816**). The increased separation distance causes the resulting radiation pattern of the antenna to have a narrower angular span (e.g., to be more directed, similar to the emission pattern **405** with angular span θ_2 in FIG. **4**B). The process **810** then returns to block **812** to emit radiation from the ground-facing antenna.

Block **814** may involve altitude determining logic receiving sensor inputs and determining altitude of the antenna, similar to the discussion of the altitude determining logic **552** in FIG. **5**A. However, the decision in block **814** may also be implicitly performed by a passive, pressure-sensitive vessel, similar to the passive altitude-sensitive linkages described in connection with FIGS. **5**B and **5**C that adjust the separation distances between radiator and reflector based on ambient pressure, which is a proxy for altitude.

If block **814** determines no increase in altitude, at block **818**, the antenna components and/or associated control systems determine whether the antenna have decreased in altitude. If the altitude is decreased, the emission pattern of the antenna is adjusted by decreasing the separation distance between the reflector and the radiator of the antenna (**820**). The decreased separation distance causes the resulting radiation pattern of the antenna to have a broader angular span (e.g., to be more dispersed, similar to the emission pattern **404** with angular span θ_1 in FIG. **4**A). The process **810** then returns to block **812** to emit radiation from the ground-facing antenna.

Similar to block **814**, block **818** may involve altitude determining logic receiving sensor inputs and determining altitude of the antenna, similar to the discussion of the altitude determining logic **552** in FIG. **5**A. However, the decision in block **818** may also be implicitly performed by a passive, pressure-sensitive vessel, similar to the passive altitude-sensitive linkages described in connection with FIGS. **5**B and **5**C that adjust the separation distances between radiator and reflector based on ambient pressure, which is a proxy for altitude.

As indicated by the dashed arrow, the process **810** can optionally be repeated to cause the emission pattern to be intermittently (or perhaps even continuously) updated according to the then present altitude of the antenna.

In some embodiments, the disclosed methods may be implemented as computer program instructions encoded on a non-transitory computer-readable storage media in a machine-readable format, or on other non-transitory media or articles of manufacture. FIG. **9** is a schematic illustrating a conceptual partial view of an example computer program product that includes a computer program for executing a computer process on a computing device, arranged according to at least some embodiments presented herein.

In one embodiment, the example computer program product **900** is provided using a signal bearing medium **902**. The signal bearing medium **902** may include one or more programming instructions **904** that, when executed by one or more processors may provide functionality or portions of the functionality described above with respect to FIGS. **1**-**8**. In some examples, the signal bearing medium **902** may encompass a computer-readable medium **906**, such as, but not limited to, a hard disk drive, a Compact Disc (CD), a Digital Video Disk (DVD), a digital tape, memory, etc. In some implementations, the signal bearing medium **902** may encompass a computer recordable medium **708**, such as, but not limited to, memory, read/write (R/W) CDs, R/W DVDs, etc. In some implementations, the signal bearing medium **902** may encompass a communications medium **910**, such as, but not limited to, a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.). Thus, for example, the signal bearing medium **902** may be conveyed by a wireless form of the communications medium **910**.

The one or more programming instructions **904** may be, for example, computer executable and/or logic implemented instructions. In some examples, a computing device such as the computer system **312** of FIG. **3** may be configured to provide various operations, functions, or actions in response to the programming instructions **904** conveyed to the computer system **312** by one or more of the computer readable medium **906**, the computer recordable medium **908**, and/or the communications medium **910**.

The non-transitory computer readable medium could also be distributed among multiple data storage elements, which could be remotely located from each other. The computing device that executes some or all of the stored instructions could be a device, such as the balloon **300** shown and described in reference to FIG. **3**. Alternatively, the computing device that executes some or all of the stored instructions could be another computing device, such as a server.

The above detailed description describes various features and functions of the disclosed systems, devices, and methods with reference to the accompanying figures. While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope being indicated by the following claims.

What is claimed is:

1. An antenna configured to be mounted to an aerial vehicle, the antenna comprising:
- a radiator configured to emit radiation according to a feed signal;
- a reflector configured to direct radiation emitted from the radiator such that reflected radiation is characterized by an emission pattern determined at least in part by a separation distance between the radiator and the reflector, wherein the reflector is configured to be situated such that the emission pattern is directed in a ground-facing direction while the aerial vehicle is aloft; and
- a linkage configured to adjust the separation distance between the radiator and the reflector according to an altitude of the aerial vehicle.

2. The antenna according to claim **1**, wherein the linkage includes a vessel arranged such that a change in volume of the vessel causes a corresponding change in the separation distance between the radiator and the reflector.

3. The antenna according to claim **2**, wherein the vessel is configured such that the volume of the vessel is based on ambient pressure, thereby causing the separation distance to be based at least in part on the ambient pressure.

4. The antenna according to claim **2**,
- wherein the vessel includes end caps connected between one or more sidewalls having a plurality of ribs to allow the vessel to change volume, in response to changes in ambient pressure, substantially by expanding or contracting a length of the one or more sidewalls, via the plurality of ribs, thereby changing a distance between the end caps, and
- wherein the end caps are connected such that the separation distance between the radiator and the reflector corresponds to the distance between the end caps.

5. The antenna according to claim **4**,
- wherein the vessel includes a generally cylindrically-shaped aneroid with at least partially corrugated metallic sidewalls, and
- wherein an internal chamber of the vessel is substantially evacuated.

6. The antenna according to claim **1**, further comprising a controller configured to: (i) determine the altitude of the aerial vehicle, and (ii) cause the linkage to adjust the separation distance between the radiator and the reflector based on the determined altitude.

7. The antenna according to claim **1**, wherein the linkage is further configured to dynamically adjust the separation distance between the radiator and the reflector by: (i) reducing the separation distance responsive to an increase in altitude of the antenna, and (ii) increasing the separation distance responsive to a decrease in altitude of the antenna.

8. The antenna according to claim **1**, wherein the separation distance is dynamically adjusted such that, in a geographical region receiving the emitted radiation at ground level, variations in intensity of the received radiation at ground level due to variations in altitude of the aerial vehicle are at least partially compensated for.

9. The antenna according to claim **1**, wherein the separation distance is dynamically adjusted such that, in a geographical region receiving the emitted radiation at ground level, variations in a boundary of the geographical region receiving the radiation due to variations in altitude of the aerial vehicle are at least partially compensated for.

10. The antenna according to claim **1**, wherein the antenna is further configured to receive radiation from a region defined by the emission pattern.

11. The antenna according to claim **1**, wherein the antenna is further configured to transmit signals to radio stations at ground level.

12. An aerial vehicle comprising:
- an envelope;
- a payload configured to be suspended from the envelope; and
- an antenna mounted to the payload and situated so as to be ground-facing while the aerial vehicle is aloft, the antenna including: (i) a radiator configured to emit radiation according to feed signals; (ii) a reflector configured to direct the radiation emitted from the radiator according to a radiation pattern determined at least in part according to a separation distance between the radiator and the reflector; and (iii) a linkage configured to adjust the separation distance between the radiator and the reflector according to an altitude of the aerial vehicle.

13. The aerial vehicle according to claim **12**, wherein the linkage includes a vessel arranged such that a change in volume of the vessel causes a corresponding change in the separation distance between the radiator and the reflector.

14. The aerial vehicle according to claim **13**, wherein the vessel is configured such that the volume of the vessel is based on ambient pressure, thereby causing the separation distance to be based, at least in part, on the ambient pressure.

15. The aerial vehicle according to claim **13**,
- wherein the vessel includes end caps connected between one or more sidewalls having a plurality of ribs to allow the vessel to change volume, in response to changes in ambient pressure, substantially by expanding or contracting a length of the one or more sidewalls, via the plurality of ribs, thereby changing a distance between the end caps,
- wherein the end caps and the one or more sidewalls enclose an inner chamber that is substantially evacuated, and
- wherein the end caps are connected such that the separation distance between the radiator and the reflector corresponds to the distance between the end caps.

16. The aerial vehicle according to claim **12**, further comprising a controller configured to: (i) determine the altitude of the aerial vehicle, and (ii) cause the linkage to adjust the separation distance between the radiator and the reflector based on the determined altitude.

17. The aerial vehicle according to claim **12**, wherein the linkage is further configured to dynamically adjust the separation distance between the radiator and the reflector by: (i) reducing the separation distance responsive to an increase in altitude of the aerial vehicle, and (ii) increasing the separation distance responsive to a decrease in altitude of the aerial vehicle.

18. A method comprising:
- emitting radiation from an antenna configured to be mounted to a payload of an associated aerial vehicle, wherein the antenna has an emission pattern determined at least in part by a separation distance between a radiator and a reflector of the antenna, and wherein

the antenna is configured to be situated such that the emission pattern is directed in a ground-facing direction while the associated aerial vehicle is aloft and the antenna is mounted to the payload;

decreasing the separation distance between the radiator and the reflector responsive to a decrease in altitude of the associated aerial vehicle; and

increasing the separation distance between the radiator and the reflector responsive to an increase in altitude of the associated aerial vehicle.

19. The method according to claim **18**, further comprising:

determining the altitude of the associated aerial vehicle; and

causing the linkage to adjust the separation distance between the radiator and the reflector based on the determined altitude.

20. The method according to claim **18**,

wherein the linkage includes a vessel arranged such that a change in volume of the vessel causes a corresponding change in the separation distance between the radiator and the reflector; and

wherein the vessel is configured such that the volume of the vessel is based on ambient pressure, thereby causing the separation distance to be based, at least in part, on the ambient pressure.

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